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A
MANUAL
OF
ELEMENTARY GEOLOGY.

By the same Author.

THE PRINCIPLES OF GEOLOGY; or, the MODERN CHANGES of the EARTH and its INHABITANTS, as illustrative of Geology. *Ninth and thoroughly revised Edition.* With Woodcuts. 8vo. 18*s.*

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LONDON:
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From a Painting by James Hall, Esq.

Engraved by S. Williams.

STRATA OF RED SANDSTONE, SLIGHTLY INCLINED, RESTING ON VERTICAL SCHIST, AT THE SICCAR POINT, NEAR ST. ABB'S HEAD, BERWICKSHIRE.

To illustrate unconformable Stratification. See Page 60.

a. Vertical Silurian schist.
a' a''. The same presenting the planes of the strata with a ripple-marked surface to the spectator.
b. Small opening in the fractured beds of overlying Old Red Sandstone through which the edges of the beds of older vertical schist are seen.
d. d. Old Red Sandstone in slightly inclined beds.

A

MANUAL

OF

ELEMENTARY GEOLOGY:

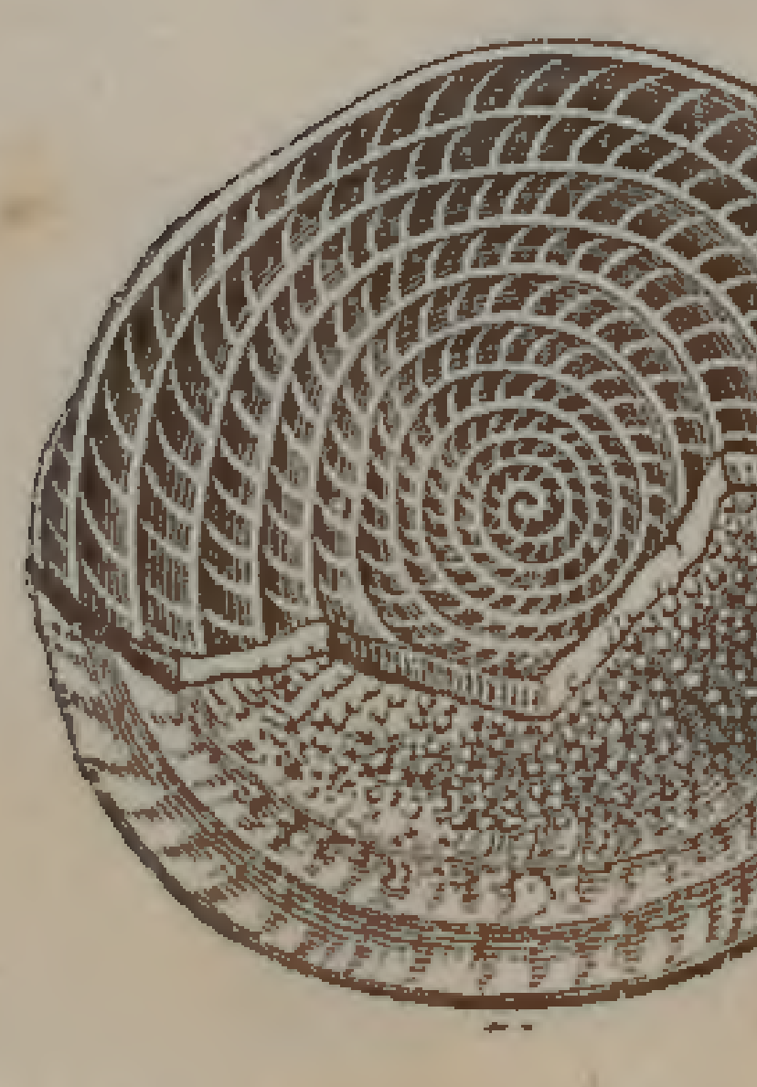
OR,

THE ANCIENT CHANGES OF THE EARTH AND ITS INHABITANTS
AS ILLUSTRATED BY GEOLOGICAL MONUMENTS.

BY SIR CHARLES LYELL, M.A. F.R.S.
AUTHOR OF "PRINCIPLES OF GEOLOGY," ETC.

> " It is a philosophy which never rests — its law is progress: a point which yesterday was invisible is its goal to-day, and will be its starting-post to-morrow."
>
> EDINBURGH REVIEW, July, 1837.

NUMMULITE.



TERTIARY.

AMMONITE.

SECONDARY.

TRILOBITE.

PRIMARY.

FIFTH EDITION, GREATLY ENLARGED, AND ILLUSTRATED WITH 750 WOODCUTS.

LONDON:
JOHN MURRAY, ALBEMARLE STREET.
1855.

PREFACE TO THE FIFTH EDITION.

It is now more than three years since the appearance of the last Edition of the Manual (published January, 1851). In that interval the science of Geology has been advancing as usual at a rapid pace, making it desirable to notice many new facts and opinions, and to consider their bearing on the previously acquired stock of knowledge. In my attempt to bring up the information contained in this Treatise to the present state of the science, I have added no less than 200 new Illustrations and 140 new pages of Text, which, if printed separately and in a less condensed form, might have constituted alone a volume of respectable size. To give in detail a list of all the minor corrections and changes would be tedious; but I have thought it useful, in order to enable the reader of former editions to direct his attention at once to what is new, to offer the following summary of the more important additions and alterations.

Principal Additions and Alterations in the present Edition.

Chap. IX. — "The general Table of Fossiliferous strata," formerly placed at the end of Chapter XXVII., is now given at p. 105., that the beginner may accustom himself from the first to refer to it from time to time when studying the numerous subdivisions into which it is now necessary to separate the chronological series of rocks. The Table has been enlarged by a column of Foreign Equivalents, comprising the names and localities of some of the best known strata in other countries of contemporaneous date with British Formations.

Chap. XIV.—XVI. — The classification of the Tertiary formations has been adapted to the information gained by me during a tour made in the summer of 1851 in France and Belgium. The results of my survey were printed in the Quarterly Journal of the Geological

Society of London for 1852. In the course of my investigations I enjoyed opportunities of determining more exactly the relations of the Antwerp and the Suffolk crag, p. 174.; the stratigraphical place of the Bolderberg beds near Hasselt, p. 179.; that of the Limburg or Kleyn Spawen strata, p. 189.; and of other Belgian and French deposits. In reference to some of these, the questions so much controverted of late, whether certain groups should be called Lower Miocene or Upper Eocene, are fully discussed, p. 184. *et seq.*

In the winter of 1852, I had the advantage of examining the northern part of the Isle of Wight, in company with my friend the late lamented Professor Edward Forbes, who pointed out to me the discoveries he had just made in regard to the true position of the Hempstead series (pp. 186—193.), recognized by him as the equivalent of the Kleyn Spawen or Limburg beds, and his new views in regard to the relation of various members of the Eocene series between the Hempstead and Bagshot beds. An account of these discoveries, with the names of the new subdivisions, is given at pp. 209. *et seq.*; the whole having been revised when in print by Edward Forbes.

The position assigned by Mr. Prestwich to the Thanet sands, as an Eocene formation inferior to the Woolwich beds, is treated of at p. 222., and the relations of the Middle and Lower Eocene of France to various deposits in the Isle of Wight and Hampshire at p. 223. *et seq.* In the same chapters, many figures have been introduced of characteristic organic remains, not given in previous editions.

Chap. XVII.—In speaking of the Cretaceous strata, I have for the first time alluded to the position of the Pisolitic Limestone in France, and other formations in Belgium intermediate between the White Chalk and Thanet beds, p. 236.

Chap. XVIII.—The Wealden beds, comprising the Weald Clay and Hastings Sands apart from the Purbeck, are in this chapter for the first time considered as belonging to the Lower Cretaceous Group, and the reasons for the change are stated at p. 264.

Chap. XIX.—Relates to "the denudation of the Weald," or of the country intervening between the North and South Downs. It has been almost entirely rewritten, and some new illustrations introduced. Many geologists have gone over that region again and again of late years, bringing to light new facts, and speculating on the probable time, extent, and causes of so vast a removal of rock. I have endeavoured to show how numerous have been the periods of denudation, how vast the duration of some of them, and how little the necessity to despair of solving the problem by an appeal to ordinary causation, or to invoke the aid of imaginary catastrophes and paroxysmal violence, pp. 272—291.

Chap. XX.—XXI.—On the strata from the Oolite to the Lias inclusive. The Purbeck beds are here for the first time considered as the uppermost member of the Oolite, in accordance with the opinions of the late Professor E. Forbes, p. 295. Many new figures of fossils characteristic of the subdivisions of the three Purbecks are introduced; and the discovery, in 1854, of a new mammifer alluded to, p. 296.

Representations also of fossils of the Upper, Middle, and Lower Oolite, and of the Lias, are added to those before given.

Chap. XXII.—XXIII. — On the Triassic and Permian formations. The improvements consist chiefly of new illustrations of fossil remains.

Chap. XXIV.—XXV. — Treating of the Carboniferous group, I have mentioned the subdivisions now generally adopted for the classification of the Irish strata (p. 362.), and I have added new figures of fossil plants to explain, among other topics, the botanical characters of Calamites, Sternbergia, and Trigonocarpum, and their relation to Coniferæ (pp. 367, 368, 371.). The grade also of the Coniferæ in the vegetable kingdom, and whether they hold a high or a low position among flowering plants, is discussed with reference to the opinions of several of the most eminent living botanists; and the bearing of these views on the theory of progressive development, p. 373.

The casts of rain-prints in coal-shale are represented in several woodcuts as illustrative of the nature and humidity of the carboniferous atmosphere, p. 384. The causes also of the purity of many seams of coal, p. 385., and the probable length of time which was required to allow the solid matter of certain coal-fields to accumulate, p. 386., are discussed for the first time.

Figures are given of Crustaceans and Insects from the Coal, pp. 388, 389.; and the discovery of some new Reptiles is alluded to, p. 405.

I have also alluded to the causes of the rarity of vertebrate and invertebrate air-breathers in the coal, p. 405.

That division of this same chapter (Chap. XXV.) which relates to the Mountain Limestone has been also enlarged by figures of new fossils, and among others by representations of Corals of the Paleozoic, as distinguishable from those of the Neozoic, type, p. 407.; also by woodcuts of several genera of shells which retain the patterns of their original colours, p. 410. The foreign equivalents of the Mountain Limestone are also alluded to, p. 413.

Chap. XXVI.—In speaking of the Old Red Sandstone, or Devonian Group, the evidence of the occurrence of the skeleton of a Reptile and the footprints of a Chelonian in that series are reconsidered, p. 416. New plants found in Ireland in this formation are figured, p. 418.; also the Pterygotus, or large crustacean of Forfarshire, p. 419.; and, lastly, the division of the Devonian series in North Devon into Upper, Middle, and Lower, p. 424., the fossils of the same (p. 425. *et seq.*), and the equivalents of the Devonian beds in Russia and the United States, are treated of, p. 429. and 432.

Chap. XXVII.—The classification and nomenclature of the Silurian rocks of Great Britain, the Continent of Europe, and North America, and the question whether they can be distinguished from the Cambrian, and by what paleontological characters, are discussed in this chapter, pp. 433. 451. and 457.

The relation of the Caradoc Sandstone to the Upper and Lower Silurian, as inferred from recent investigations (p. 441.), the vast thickness of the Llandeilo or Lower Silurian in Wales (p. 446.), the Obolus or Ungulite grit of St. Petersburg and its fossils (p. 447.), the Silurian strata of the United States and their British equivalents (p. 448.), and those of Canada, the discoveries of M. Barrande respecting the metamorphosis of Silurian and Cambrian trilobites (pp. 445. 454.), are among the subjects enlarged upon more fully than in former editions, or now treated of for the first time.

The Cambrian beds below the Llandeilo, and their fossils, are likewise described as they exist in Wales, Ireland, Bohemia, Sweden, the United States, and Canada, and some of their peculiar organic remains are figured, p. 451. to p. 457.

Lastly, at the conclusion of the chapter, some remarks are offered respecting the absence of the remains of fish and other vertebrata from the deposits below the Upper Silurian, p. 457., in elucidation of which topic a Table has been drawn up of the dates of the successive discovery of different classes of Fossil Vertebrata in rocks of higher and higher antiquity, showing the gradual progress made in the course of the last century and a half in tracing back each class to more and more ancient rocks. The bearing of the positive and negative facts thus set forth on the doctrine of progressive development is then discussed, and the grounds of the supposed scarcity both of vertebrate and invertebrate air-breathers in the most ancient formation considered, p. 460.

Chap. XXVIII.—With the assistance of an able mineralogist, M. Delesse, I have revised and enlarged the glossary of the more abundant volcanic rocks, p. 476., and the table of analyses of simple minerals, p. 479.

Chap. XXIX.—In consequence of a geological excursion to Madeira and the Canary Islands, which I made in the winter of 1853-4, I have been enabled to make larger additions of original matter to this chapter than to any other in the work. The account of Teneriffe and Madeira, pp. 514. 522., is wholly new. Formerly I gave an abstract of Von Buch's description of the island of Palma, one of the Canaries, but I have now treated of it more fully from my own observations, regarding Palma as a good type of that class of volcanic mountains which have been called by Von Buch "craters of elevation," pp. 498—512. Many illustrations, chiefly from the pencil of my companion and fellow-labourer, Mr. Hartung, have been introduced. In reference to the above-mentioned subjects, citations are made from Dana on the Sandwich Islands, p. 493., and from Junghuhn's Java, p. 496.

CHAP. XXXV.—XXXVII. — The theory of the origin of the metamorphic rocks and certain views recently put forward by some geologists respecting cleavage and foliation have made it desirable to recast and rewrite a portion of these chapters. New proofs are cited in favour of attributing cleavage to mechanical force, p. 610., and for inferring in many cases a connection between foliation and cleavage, p. 615. At the same time, the question—how far the planes of foliation usually agree with those of sedimentary deposition, is entered into, p. 614.

CHAP. XXXVIII. — To the account formerly published of mineral veins some facts and opinions are added respecting the age of the rocks and alluvial deposits containing gold in South America, the United States, California, and Australia.

I have already alluded to the assistance afforded me by the late Professor Edward Forbes towards the improvement of some parts of this work. His letters suggesting corrections and additions were continued to within a few weeks of his sudden and unexpected death, and I felt most grateful to him for the warm interest, which, in the midst of so many and pressing avocations, he took in the success of my labours. His friendship and the power of referring to his sound judgment in cases of difficulty on palæontological and other questions were among the highest privileges I have ever enjoyed in the course of my scientific pursuits. Never perhaps has it been the lot of any Englishman, who had not attained to political or literary eminence, more especially one who had not reached his fortieth year, to engage the sympathies of so wide a circle of admirers, and to be so generally mourned. The untimely death of such a teacher was justly felt to be a national loss; for there was a deep conviction in the minds of all who knew him, that genius of so high an order, combined with vast acquirements, true independence of character, and so many social and moral excellencies, would have inspired a large portion of the rising generation with kindred enthusiasm for branches of knowledge hitherto neglected in the education of British youth.

As on former occasions, I shall take this opportunity of stating that the "Manual" is not an epitome of the "Principles of Geology," nor intended as introductory to that work. So much confusion has arisen on this subject, that it is desirable to explain fully the different ground occupied by the two publications. The first five editions of the "Principles" comprised a 4th book, in which some account was given of systematic geology, and in which the principal rocks composing the earth's crust and their organic remains were described. In subsequent editions this 4th book was omitted, it having been expanded, in 1838, into a separate treatise called the "Elements of Geology," first re-edited in 1842, and again recast and enlarged in 1851, and entitled "A Manual of Elementary Geology." Of this enlarged work another edition, called the Fourth, was published in 1852.

Although the subjects of both treatises relate to Geology, as their titles imply, their scope is very different; the "Principles" containing a view of the *modern* changes of the earth and its inhabitants, while the "Manual" relates to the monuments of *ancient* changes. In separating the one from the other, I have endeavoured to render each complete in itself, and independent; but if asked by a student which he should read first, I would recommend him to begin with the "Principles," as he may then proceed from the known to the unknown, and be provided beforehand with a key for interpreting the ancient phenomena, whether of the organic or inorganic world, by reference to changes now in progress.

It will be seen on comparing "The Contents" of the "Principles" with the abridged headings of the chapters of the present work (see the following pages), that the two treatises have but little in common; or, to repeat what I have said in the Preface to the "Principles," they have the same kind of connection which Chemistry bears to Natural Philosophy, each being subsidiary to the other, and yet admitting of being considered as different departments of science.*

CHARLES LYELL.

53. *Harley Street, London, February* 22. 1855.

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* As it is impossible to enable the reader to recognize rocks and minerals at sight by aid of verbal descriptions or figures, he will do well to obtain a well-arranged collection of specimens, such as may be procured from Mr. Tennant (149. Strand), teacher of Mineralogy at King's College, London.

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MANUAL
OF
ELEMENTARY GEOLOGY.

CHAPTER I.

ON THE DIFFERENT CLASSES OF ROCKS.

Geology defined — Successive formation of the earth's crust — Classification of rocks according to their origin and age — Aqueous rocks — Their stratification and imbedded fossils — Volcanic rocks, with and without cones and craters — Plutonic rocks, and their relation to the volcanic — Metamorphic rocks, and their probable origin — The term primitive, why erroneously applied to the crystalline formations — Leading division of the work.

Of what materials is the earth composed, and in what manner are these materials arranged? These are the first inquiries with which Geology is occupied, a science which derives its name from the Greek γῆ, *ge*, the earth, and λογος, *logos*, a discourse. Previously to experience we might have imagined that investigations of this kind would relate exclusively to the mineral kingdom, and to the various rocks, soils, and metals, which occur upon the surface of the earth, or at various depths beneath it. But, in pursuing such researches, we soon find ourselves led on to consider the successive changes which have taken place in the former state of the earth's surface and interior, and the causes which have given rise to these changes; and, what is still more singular and unexpected, we soon become engaged in researches into the history of the animate creation, or of the various tribes of animals and plants which have, at different periods of the past, inhabited the globe.

All are aware that the solid parts of the earth consist of distinct substances, such as clay, chalk, sand, limestone, coal, slate, granite, and the like; but previously to observation it is commonly imagined that all these had remained from the first in the state in which we now see them,—that they were created in their present form, and in their present position. The geologist soon comes to a different conclusion, discovering proofs that the external parts of the earth were not all produced in the beginning of things in the state in which we now behold them, nor in an instant of time. On the contrary, he can show that they have acquired their actual configuration and condition gradually, under a great variety of circumstances, and at successive periods, during each of which distinct races of living beings have flourished on the land and in the waters, the remains of these creatures still lying buried in the crust of the earth.

By the "earth's crust," is meant that small portion of the exterior of our planet which is accessible to human observation, or on which we are enabled to reason by observations made at or near the surface. These reasonings may extend to a depth of several miles, perhaps ten miles; and even then it may be said, that such a thickness is no more than $\frac{1}{400}$ part of the distance from the surface to the centre. The remark is just; but although the dimensions of such a crust are, in truth, insignificant when compared to the entire globe, yet they are vast, and of magnificent extent in relation to man, and to the organic beings which people our globe. Referring to this standard of magnitude, the geologist may admire the ample limits of his domain, and admit, at the same time, that not only the exterior of the planet, but the entire earth, is but an atom in the midst of the countless worlds surveyed by the astronomer.

The materials of this crust are not thrown together confusedly; but distinct mineral masses, called rocks, are found to occupy definite spaces, and to exhibit a certain order of arrangement. The term *rock* is applied indifferently by geologists to all these substances, whether they be soft or stony, for clay and sand are included in the term, and some have even brought peat under this denomination. Our older writers endeavoured to avoid offering such violence to our language, by speaking of the component materials of the earth as consisting of rocks and *soils*. But there is often so insensible a passage from a soft and incoherent state to that of stone, that geologists of all countries have found it indispensable to have one technical term to include both, and in this sense we find *roche* applied in French, *rocca* in Italian, and *felsart* in German. The beginner, however, must constantly bear in mind, that the term rock by no means implies that a mineral mass is in an indurated or stony condition.

The most natural and convenient mode of classifying the various rocks which compose the earth's crust, is to refer, in the first place, to their origin, and in the second to their relative age. I shall therefore begin by endeavouring briefly to explain to the student how all rocks may be divided into four great classes by reference to their different origin, or, in other words, by reference to the different circumstances and causes by which they have been produced.

The first two divisions, which will at once be understood as natural, are the aqueous and volcanic, or the products of watery and those of igneous action at or near the surface.

Aqueous rocks.—The aqueous rocks, sometimes called the sedimentary, or fossiliferous, cover a larger part of the earth's surface than any others. These rocks are *stratified*, or divided into distinct layers, or strata. The term *stratum* means simply a bed, or any thing spread out or *strewed* over a given surface; and we infer that these strata have been generally spread out by the action of water, from what we daily see taking place near the mouths of rivers, or on the land during temporary inundations. For, whenever a running stream charged with mud or sand, has its velocity checked, as when it enters a lake or sea, or overflows a plain, the sediment, previously held in suspension by the motion of the water, sinks, by its own gravity, to the bottom. In this manner layers of mud and sand are thrown down one upon another.

If we drain a lake which has been fed by a small stream, we frequently find at the bottom a series of deposits, disposed with considerable regularity, one above the other; the uppermost, perhaps, may be a stratum of peat, next below a more dense and solid variety of the same material; still lower a bed of shell-marl, alternating with peat or sand, and then other beds of marl, divided by layers of clay. Now, if a second pit be sunk through the same continuous lacustrine *formation*, at some distance from the first, nearly the same series of beds is commonly met with, yet with slight variations; some, for example, of the layers of sand, clay, or marl, may be wanting, one or more of them having thinned out and given place to others, or sometimes one of the masses first examined is observed to increase in thickness to the exclusion of other beds.

The term "*formation*," which I have used in the above explanation, expresses in geology any assemblage of rocks which have some character in common, whether of origin, age, or composition. Thus we speak of stratified and unstratified, freshwater and marine, aqueous and volcanic, ancient and modern, metalliferous and non-metalliferous formations.

In the estuaries of large rivers, such as the Ganges and the Mississippi, we may observe, at low water, phenomena analogous to those of the drained lakes above mentioned, but on a grander scale, and extending over areas several hundred miles in length and breadth. When the periodical inundations subside, the river hollows out a channel to the depth of many yards through horizontal beds of clay and sand, the ends of which are seen exposed in perpendicular cliffs. These beds vary in their mineral composition, or colour, or in the fineness or coarseness of their particles, and some of them are occasionally characterized by containing drift wood. At the junction of the river and the sea, especially in lagoons nearly separated by sand bars from the ocean, deposits are often formed in which brackish-water and salt-water shells are included.

The annual floods of the Nile in Egypt are well known, and the fertile deposits of mud which they leave on the plains. This mud is *stratified*, the thin layer thrown down in one season differing slightly in colour from that of a previous year, and being separable from it, as has been observed in excavations at Cairo, and other places.*

When beds of sand, clay, and marl, containing shells and vegetable matter, are found arranged in a similar manner in the interior of the earth, we ascribe to them a similar origin; and the more we examine their characters in minute detail, the more exact do we find the resemblance. Thus, for example, at various heights and depths in the

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* See Principles of Geology, by the Author, Index, "Nile," "Rivers," &c.

earth, and often far from seas, lakes, and rivers, we meet with layers of rounded pebbles composed of flint, limestone, granite, or other rocks, resembling the shingles of a sea-beach or the gravel in a torrent's bed. Such layers of pebbles frequently alternate with others formed of sand or fine sediment, just as we may see in the channel of a river descending from hills bordering a coast, where the current sweeps down at one season coarse sand and gravel, while at another, when the waters are low and less rapid, fine mud and sand alone are carried seaward.*

If a stratified arrangement, and the rounded form of pebbles, are alone sufficient to lead us to the conclusion that certain rocks originated under water, this opinion is farther confirmed by the distinct and independent evidence of *fossils*, so abundantly included in the earth's crust. By a *fossil* is meant any body, or the traces of the existence of any body, whether animal or vegetable, which has been buried in the earth by natural causes. Now the remains of animals, especially of aquatic species, are found almost everywhere imbedded, in stratified rocks, and sometimes, in the case of limestone, they are in such abundance as to constitute the entire mass of the rock itself. Shells and corals are the most frequent, and with them are often associated the bones and teeth of fishes, fragments of wood, impressions of leaves, and other organic substances. Fossil shells, of forms such as now abound in the sea, are met with far inland, both near the surface, and at great depths below it. They occur at all heights above the level of the ocean, having been observed at elevations of more than 8000 feet in the Pyrenees, 10,000 in the Alps, 13,000 in the Andes, and above 18,000 feet in the Himalaya.†

These shells belong mostly to marine testacea, but in some places exclusively to forms characteristic of lakes and rivers. Hence it is concluded that some ancient strata were deposited at the bottom of the sea, and others in lakes and estuaries.

When geology was first cultivated, it was a general belief, that these marine shells and other fossils were the effects and proofs of the deluge of Noah; but all who have carefully investigated the phenomena have long rejected this doctrine. A transient flood might be supposed to leave behind it, here and there upon the surface, scattered heaps of mud, sand, and shingle, with shells confusedly intermixed; but the strata containing fossils are not superficial deposits, and do not simply cover the earth, but constitute the entire mass of mountains. Nor are the fossils mingled without reference to the original habits and natures of the creatures of which they are the memorials; those, for example, being found associated together which lived in deep or in shallow water, near the shore or far from it, in brackish or in salt water.

It has, moreover, been a favourite notion of some modern writers, who were aware that fossil bodies could not all be referred to the deluge, that they, and the strata in which they are entombed, might

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* See p. 18. fig. 7.

† Capt. R. J. Strachey found oolitic fossils 18,400 feet high in the Himalaya.

have been deposited in the bed of the ocean during the period which intervened between the creation of man and the deluge. They have imagined that the antediluvian bed of the ocean, after having been the receptacle of many stratified deposits, became converted, at the time of the flood, into the lands which we inhabit, and that the ancient continents were at the same time submerged, and became the bed of the present seas. This hypothesis, although preferable to the diluvial theory before alluded to, since it admits that all fossiliferous strata were successively thrown down from water, is yet wholly inadequate to explain the repeated revolutions which the earth has undergone, and the signs which the existing continents exhibit, in most regions, of having emerged from the ocean at an era far more remote than four thousand years from the present time. Ample proofs of these reiterated revolutions will be given in the sequel, and it will be seen that many distinct sets of sedimentary strata, hundreds and sometimes thousands of feet thick, are piled one upon the other in the earth's crust, each containing peculiar fossil animals and plants of species distinguishable for the most part from all those now living. The mass of some of these strata consists almost entirely of corals, others are made up of shells, others of plants turned into coal, while some are without fossils. In one set of strata the species of fossils are marine; in another, lying immediately above or below, they as clearly prove that the deposit was formed in a lake or in a brackish estuary. When the student has more fully examined into these appearances, he will become convinced that the time required for the origin of the rocks composing the actual continents must have been far greater than that which is conceded by the theory above alluded to; and likewise that no one universal or sudden conversion of sea into land will account for geological appearances.

We have now pointed out one great class of rocks, which, however they may vary in mineral composition, colour, grain, or other characters, external and internal, may nevertheless be grouped together as having a common origin. They have all been formed under water, in the same manner as modern accumulations of sand, mud, shingle, banks of shells, reefs of coral, and the like, and are all characterised by stratification or fossils, or by both.

Volcanic rocks.—The division of rocks which we may next consider are the volcanic, or those which have been produced at or near the surface whether in ancient or modern times, not by water, but by the action of fire or subterranean heat. These rocks are for the most part unstratified, and are devoid of fossils. They are more partially distributed than aqueous formations, at least in respect to horizontal extension. Among those parts of Europe where they exhibit characters not to be mistaken, I may mention not only Sicily and the country round Naples, but Auvergne, Velay, and Vivarais, now the departments of Puy de Dome, Haute Loire, and Ardêche, towards the centre and south of France, in which are several hundred conical hills having the forms of modern volcanos, with craters more or less perfect on many of their summits. These cones are composed more over of lava, sand, and ashes, similar to those of active volcanos. Streams of lava may sometimes be traced from the cones into the adjoining valleys, where they have choked up the ancient channels of rivers with solid rock, in the same manner as some modern flows of lava in Iceland have been known to do, the rivers either flowing beneath or cutting out a narrow passage on one side of the lava. Although none of these French volcanos have been in activity within the period of history or tradition, their forms are often very perfect. Some, however, have been compared to the mere skeletons of volcanos, the rains and torrents having washed their sides, and removed all the loose sand and scoriæ, leaving only the harder and more solid materials. By this erosion, and by earthquakes, their internal structure has occasionally been laid open to view, in fissures and ravines; and we then behold not only many successive beds and masses of porous lava, sand, and scoriæ, but also perpendicular walls, or *dikes*, as they are called, of volcanic rock, which have burst through the other materials. Such dikes are also observed in the structure of Vesuvius, Etna, and other active volcanos. They have been formed by the pouring of melted matter, whether from above or below, into open fissures, and they commonly traverse deposits of *volcanic tuff*, a substance produced by the showering down from the air, or incumbent waters, of sand and cinders, first shot up from the interior of the earth by the explosions of volcanic gases.

Besides the parts of France above alluded to, there are other countries, as the north of Spain, the south of Sicily, the Tuscan territory of Italy, the lower Rhenish provinces, and Hungary, where spent volcanos may be seen, still preserving in many cases a conical form, and having craters and often lava-streams connected with them.

There are also other rocks in England, Scotland, Ireland, and almost every country in Europe, which we infer to be of igneous origin, although they do not form hills with cones and craters. Thus, for example, we feel assured that the rock of Staffa, and that of the Giant's Causeway, called basalt, is volcanic, because it agrees in its columnar structure and mineral composition with streams of lava which we know to have flowed from the craters of volcanos. We find also similar basaltic and other igneous rocks associated with beds of *tuff* in various parts of the British Isles, and forming *dikes*, such as have been spoken of; and some of the strata through which these dikes cut are occasionally altered at the point of contact, as if they had been exposed to the intense heat of melted matter.

The absence of cones and craters, and long narrow streams of superficial lava, in England and many other countries, is principally to be attributed to the eruptions having been submarine, just as a considerable proportion of volcanos in our own times burst out beneath the sea. But this question must be enlarged upon more fully in the chapters on Igneous Rocks, in which it will also be shown, that as different sedimentary formations, containing each their characteristic fossils, have been deposited at successive periods, so also volcanic sand and scoriæ have been thrown out, and lavas have flowed over the land or bed of the sea, at many different epochs, or have been injected into fissures; so that the igneous as well as the aqueous rocks may be classed as a chronological series of monuments, throwing light on a succession of events in the history of the earth.

Plutonic rocks (Granite, &c.).—We have now pointed out the existence of two distinct orders of mineral masses, the aqueous and the volcanic: but if we examine a large portion of a continent, especially if it contain within it a lofty mountain range, we rarely fail to discover two other classes of rocks, very distinct from either of those above alluded to, and which we can neither assimilate to deposits such as are now accumulated in lakes or seas, nor to those generated by ordinary volcanic action. The members of both these divisions of rocks agree in being highly crystalline and destitute of organic remains. The rocks of one division have been called plutonic, comprehending all the granites and certain porphyries, which are nearly allied in some of their characters to volcanic formations. The members of the other class are stratified and often slaty, and have been called by some the *crystalline schists*, in which group are included gneiss, micaceous-schist (or mica-slate), hornblende-schist, statuary marble, the finer kinds of roofing slate, and other rocks afterwards to be described.

As it is admitted that nothing strictly analogous to these crystalline productions can now be seen in the progress of formation on the earth's surface, it will naturally be asked, on what data we can find a place for them in a system of classification founded on the origin of rocks. I cannot, in reply to this question, pretend to give the student, in a few words, an intelligible account of the long chain of facts and reasonings by which geologists have been led to infer the analogy of the rocks in question to others now in progress at the surface. The result, however, may be briefly stated. All the various kinds of granite which constitute the plutonic family, are supposed to be of igneous origin, but to have been formed under great pressure, at a considerable depth in the earth, or sometimes, perhaps, under a certain weight of incumbent water. Like the lava of volcanos, they have been melted, and have afterwards cooled and crystallised, but with extreme slowness, and under conditions very different from those of bodies cooling in the open air. Hence they differ from the volcanic rocks, not only by their more crystalline texture, but also by the absence of tuffs and breccias, which are the products of eruptions at the earth's surface, or beneath seas of inconsiderable depth. They differ also by the absence of pores or cellular cavities, to which the expansion of the entangled gases gives rise in ordinary lava.

Although granite has often pierced through other strata, it has rarely, if ever, been observed to rest upon them, as if it had overflowed. But as this is continually the case with the volcanic rocks, they have been styled, from this peculiarity, "overlying" by Dr. Mac Culloch; and Mr. Necker has proposed the term "underlying" for the granites, to designate the opposite mode in which they almost invariably present themselves.

Metamorphic, or stratified crystalline rocks.—The fourth and last great division of rocks are the crystalline strata and slates, or schists, called gneiss, mica-schist, clay-slate, chlorite-schist, marble, and the like, the origin of which is more doubtful than that of the other three classes. They contain no pebbles, or sand, or scoriæ, or angular pieces of imbedded stone, and no traces of organic bodies, and they are often as crystalline as granite, yet are divided into beds, corresponding in form and arrangement to those of sedimentary formations, and are therefore said to be stratified. The beds sometimes consist of an alternation of substances varying in colour, composition, and thickness, precisely as we see in stratified fossiliferous deposits. According to the Huttonian theory, which I adopt as the most probable, and which will be afterwards more fully explained, the materials of these strata were originally deposited from water in the usual form of sediment, but they were subsequently so altered by subterranean heat, as to assume a new texture. It is demonstrable, in some cases at least, that such a complete conversion has actually taken place, fossiliferous strata having exchanged an earthy for a highly crystalline texture for a distance of a quarter of a mile from their contact with granite. In some cases, dark limestones, replete with shells and corals, have been turned into white statuary marble, and hard clays, containing vegetable or other remains, into slates called mica-schist or hornblende-schist, every vestige of the organic bodies having been obliterated.

Although we are in a great degree ignorant of the precise nature of the influence exerted in these cases, yet it evidently bears some analogy to that which volcanic heat and gases are known to produce; and the action may be conveniently called plutonic, because it appears to have been developed in those regions where plutonic rocks are generated, and under similar circumstances of pressure and depth in the earth. Whether hot water or steam permeating stratified masses, or electricity, or any other causes have co-operated to produce the crystalline texture, may be matter of speculation, but it is clear that the plutonic influence has sometimes pervaded entire mountain masses of strata.

In accordance with the hypothesis above alluded to, I proposed in the first edition of the Principles of Geology (1833), the term "Metamorphic" for the altered strata, a term derived from μετα, meta, *trans*, and μορφη, morphe, *forma*.

Hence there are four great classes of rocks considered in reference to their origin,—the aqueous, the volcanic, the plutonic, and the metamorphic. In the course of this work it will be shown, that portions of each of these four distinct classes have originated at many successive periods. They have all been produced contemporaneously, and may even now be in the progress of formation on a large scale. It is not true, as was formerly supposed, that all granites, together with the crystalline or metamorphic strata, were first formed, and therefore entitled to be called "primitive," and that the aqueous and volcanic rocks were afterwards super-imposed, and should, therefore, rank as secondary in the order of time. This idea was adopted in the infancy of the science, when all formations, whether stratified or unstratified, earthy or crystalline, with or without fossils, were alike regarded as of aqueous origin. At that period it was naturally argued, that the foundation must be older than the superstructure; but it was afterwards discovered, that this opinion was by no means in every instance a legitimate deduction from facts; for the inferior parts of the earth's crust have often been modified, and even entirely changed, by the influence of volcanic and other subterranean causes, while super-imposed formations have not been in the slightest degree altered. In other words, the destroying and renovating processes have given birth to new rocks below, while those above, whether crystalline or fossiliferous, have remained in their ancient condition. Even in cities, such as Venice and Amsterdam, it cannot be laid down as universally true, that the upper parts of each edifice, whether of brick or marble, are more modern than the foundations on which they rest, for these often consist of wooden piles, which may have rotted and been replaced one after the other, without the least injury to the buildings above; meanwhile, these may have required scarcely any repair, and may have been constantly inhabited. So it is with the habitable surface of our globe, in its relation to large masses of rock immediately below: it may continue the same for ages, while subjacent materials, at a great depth, are passing from a solid to a fluid state, and then reconsolidating, so as to acquire a new texture.

As all the crystalline rocks may, in some respects, be viewed as belonging to one great family, whether they be stratified or unstratified, plutonic or metamorphic, it will often be convenient to speak of them by one common name. It being now ascertained, as above stated, that they are of very different ages, sometimes newer than the strata called secondary, the terms primitive and primary which were formerly used for the whole must be abandoned, as they would imply a manifest contradiction. It is indispensable, therefore, to find a new name, one which must not be of chronological import, and must express, on the one hand, some peculiarity equally attributable to granite and gneiss (to the plutonic as well as the *altered* rocks), and, on the other, must have reference to characters in which those rocks differ, both from the volcanic and from the *unaltered* sedimentary strata. I proposed in the Principles of Geology (first edition, vol. iii.), the term "hypogene" for this purpose, derived from ὑπο, *under*, and γινομαι, *to be*, or *to be born;* a word implying the theory that granite, gneiss, and the other crystalline formations are alike *netherformed* rocks, or rocks which have not assumed their present form and structure at the surface. They occupy the lowest place in the order of superposition. Even in regions such as the Alps, where some masses of granite and gneiss can be shown to be of comparatively modern date, belonging, for example, to the period hereafter to be described as tertiary, they are still *underlying* rocks, They never repose on the volcanic or trappean formations, nor on strata containing organic remains. They are *hypogene*, as "being under" all the rest.

From what has now been said, the reader will understand that each of the four great classes of rocks may be studied under two distinct points of view; first, they may be studied simply as mineral masses deriving their origin from particular causes, and having a certain composition, form, and position in the earth's crust, or other characters both positive and negative, such as the presence or absence of organic remains. In the second place, the rocks of each class may be viewed as a grand chronological series of monuments, attesting a succession of events in the former history of the globe and its living inhabitants.

I shall accordingly proceed to treat of each family of rocks; first, in reference to those characters which are not chronological, and then in particular relation to the several periods when they were formed.

CHAPTER II.

AQUEOUS ROCKS — THEIR COMPOSITION AND FORMS OF STRATIFICATION.

Mineral composition of strata — Arenaceous rocks — Argillaceous — Calcareous — Gypsum — Forms of stratification — Original horizontality — Thinning out — Diagonal arrangement — Ripple mark.

IN pursuance of the arrangement explained in the last chapter, we shall begin by examining the aqueous or sedimentary rocks, which are for the most part distinctly stratified, and contain fossils. We may first study them with reference to their mineral composition, external appearance, position, mode of origin, organic contents, and other characters which belong to them as aqueous formations, independently of their age, and we may afterwards consider them chronologically or with reference to the successive geological periods when they originated.

I have already given an outline of the data which led to the belief that the stratified and fossiliferous rocks were originally deposited under water; but, before entering into a more detailed investigation, it will be desirable to say something of the ordinary materials of which such strata are composed. These may be said to belong principally to three divisions, the arenaceous, the argillaceous, and the calcareous, which are formed respectively of sand, clay, and carbonate of lime. Of these, the arenaceous, or sandy masses, are chiefly made up of siliceous or flinty grains; the argillaceous, or clayey, of a mixture of siliceous matter, with a certain proportion, about a fourth in weight, of aluminous earth; and, lastly, the calcareous rocks or limestones consist of carbonic acid and lime.

Arenaceous or siliceous rocks. — To speak first of the sandy division: beds of loose sand are frequently met with, of which the grains consist entirely of silex, which term comprehends all purely siliceous minerals, as quartz and common flint. Quartz is silex in its purest form. Flint usually contains some admixture of alumine and oxide of iron. The siliceous grains in sand are usually rounded, as if by the action of running water. Sandstone is an aggregate of such grains, which often cohere together without any visible cement, but more commonly are bound together by a slight quantity of siliceous or calcareous matter, or by iron or clay.

Pure siliceous rocks may be known by not effervescing when a drop of nitric, sulphuric or other acid is applied to them, or by the grains not being readily scratched or broken by ordinary pressure. In nature there is every intermediate gradation, from perfectly loose sand, to the hardest sandstone. In *micaceous sandstones* mica is very abundant; and the thin silvery plates into which that mineral divides, are often arranged in layers parallel to the planes of stratification, giving a slaty or laminated texture to the rock.

When sandstone is coarse-grained, it is usually called *grit.* If the grains are rounded, and large enough to be called pebbles, it becomes a *conglomerate* or *pudding-stone*, which may consist of pieces of one or of many different kinds of rock. A conglomerate, therefore, is simply gravel bound together by a cement.

Argillaceous rocks. — Clay, strictly speaking, is a mixture of silex or flint with a large proportion, usually about one fourth, of alumine, or argil; but in common language, any earth which possesses sufficient ductility, when kneaded up with water, to be fashioned like paste by the hand, or by the potter's lathe, is called a *clay;* and such clays vary greatly in their composition, and are, in general, nothing more than mud derived from the decomposition or wearing down of rocks. The purest clay found in nature is porcelain clay, or kaolin, which results from the decomposition of a rock composed of felspar and quartz, and it is almost always mixed with quartz.* *Shale* has also the property, like clay, of becoming plastic in water: it is a more solid form of clay, or argillaceous matter, condensed by pressure. It usually divides into laminæ more or less regular.

One general character of all argillaceous rocks is to give out a peculiar, earthy odour when breathed upon, which is a test of the presence of alumine, although it does not belong to pure alumine, but, apparently, to the combination of that substance with oxide of iron.†

Calcareous rocks. — This division comprehends those rocks which, like chalk, are composed chiefly of lime and carbonic acid. Shells and corals are also formed of the same elements, with the addition

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* The kaolin of China consists of 71·15 parts of silex, 15·86 of alumine, 1·92 of lime, and 6·73 of water (W. Phillips, Mineralogy, p. 33.); but other porcelain clays differ materially, that of Cornwall being composed, according to Boase, of nearly equal parts of silica and alumine, with 1 per cent. of magnesia. (Phil. Mag. vol. x. 1837.)

† See W. Phillips's Mineralogy, "Alumine."

of animal matter. To obtain pure lime it is necessary to calcine these calcareous substances, that is to say, to expose them to heat of sufficient intensity to drive off the carbonic acid, and other volatile matter. White chalk is sometimes pure carbonate of lime; and this rock, although usually in a soft and earthy state, is occasionally sufficiently solid to be used for building, and even passes into a *compact* stone, or a stone of which the separate parts are so minute as not to be distinguishable from each other by the naked eye.

Many limestones are made up entirely of minute fragments of shells and coral, or of calcareous sand cemented together. These last might be called "calcareous sandstones;" but that term is more properly applied to a rock in which the grains are partly calcareous and partly siliceous, or to quartzose sandstones, having a cement of carbonate of lime.

The variety of limestone called "oolite" is composed of numerous small egg-like grains, resembling the roe of a fish, each of which has usually a small fragment of sand as a nucleus, around which concentric layers of calcareous matter have accumulated.

Any limestone which is sufficiently hard to take a fine polish is called *marble*. Many of these are fossiliferous; but statuary marble, which is also called saccharine limestone, as having a texture resembling that of loaf-sugar, is devoid of fossils, and is in many cases a member of the metamorphic series.

Siliceous limestone is an intimate mixture of carbonate of lime and flint, and is harder in proportion as the flinty matter predominates.

The presence of carbonate of lime in a rock may be ascertained by applying to the surface a small drop of diluted sulphuric, nitric, or muriatic acids, or strong vinegar; for the lime, having a greater chemical affinity for any one of these acids than for the carbonic, unites immediately with them to form new compounds, thereby becoming a sulphate, nitrate, or muriate of lime. The carbonic acid, when thus liberated from its union with the lime, escapes in a gaseous form, and froths up or effervesces as it makes its way in small bubbles through the drop of liquid. This effervescence is brisk or feeble in proportion as the limestone is pure or impure, or, in other words, according to the quantity of foreign matter mixed with the carbonate of lime. Without the aid of this test, the most experienced eye cannot always detect the presence of carbonate of lime in rocks.

The above-mentioned three classes of rocks, the siliceous, argillaceous, and calcareous, pass continually into each other, and rarely occur in a perfectly separate and pure form. Thus it is an exception to the general rule to meet with a limestone as pure as ordinary white chalk, or with clay as aluminous as that used in Cornwall for porcelain, or with sand so entirely composed of siliceous grains as the white sand of Alum Bay in the Isle of Wight, or sandstone so pure as the grit of Fontainebleau, used for pavement in France. More commonly we find sand and clay, or clay and marl, intermixed in the same mass. When the sand and clay are each in considerable quantity, the mixture is called *loam*. If there is much calcareous matter in clay it is called *marl;* but this term has unfortunately been used so vaguely, as often to be very ambiguous. It has been applied to substances in which there is no lime; as, to that red loam usually called red marl in certain parts of England. Agriculturists were in the habit of calling any soil a marl, which, like true marl, fell to pieces readily on exposure to the air. Hence arose the confusion of using this name for soils which, consisting of loam, were easily worked by the plough, though devoid of lime.

Marl slate bears the same relation to marl which shale bears to clay, being a calcareous shale. It is very abundant in some countries, as in the Swiss Alps. Argillaceous or marly limestone is also of common occurrence.

There are few other kinds of rock which enter so largely into the composition of sedimentary strata as to make it necessary to dwell here on their characters. I may, however, mention two others,—magnesian limestone or dolomite, and gypsum. *Magnesian limestone* is composed of carbonate of lime and carbonate of magnesia; the proportion of the latter amounting in some cases to nearly one half. It effervesces much more slowly and feebly with acids than common limestone. In England this rock is generally of a yellowish colour; but it varies greatly in mineralogical character, passing from an earthy state to a white compact stone of great hardness. *Dolomite*, so common in many parts of Germany and France, is also a variety of magnesian limestone, usually of a granular texture.

Gypsum.—Gypsum is a rock composed of sulphuric acid, lime, and water. It is usually a soft whitish-yellow rock, with a texture resembling that of loaf-sugar, but sometimes it is entirely composed of lenticular crystals. It is insoluble in acids, and does not effervesce like chalk and dolomite, because it does not contain carbonic acid gas, or fixed air, the lime being already combined with sulphuric acid, for which it has a stronger affinity than for any other. Anhydrous gypsum is a rare variety, into which water does not enter as a component part. Gypseous marl is a mixture of gypsum and marl. Alabaster is a granular and compact variety of gypsum found in masses large enough to be used in sculpture and architecture. It is sometimes a pure snow-white substance, as that of Volterra in Tuscany, well known as being carved for works of art in Florence and Leghorn. It is a softer stone than marble, and more easily wrought.

Forms of stratification.—A series of strata sometimes consists of one of the above rocks, sometimes of two or more in alternating beds.

Thus, in the coal districts of England, for example, we often pass through several beds of sandstone, some of finer, others of coarser grain, some white, others of a dark colour, and below these, layers of shale and sandstone or beds of shale, divisible into leaf-like laminæ, and containing beautiful impressions of plants. Then again we meet with beds of pure and impure coal, alternating with shales and sandstones, and underneath the whole, perhaps, are calcareous strata, or beds of limestone, filled with corals and marine shells, each bed distinguishable from another by certain fossils, or by the abundance of particular species of shells or zoophytes.

This alternation of different kinds of rock produces the most distinct stratification; and we often find beds of limestone and marl, conglomerate and sandstone, sand and clay, recurring again and again, in nearly regular order, throughout a series of many hundred strata. The causes which may produce these phenomena are various, and have been fully discussed in my treatise on the modern changes of the earth's surface.* It is there seen that rivers flowing into lakes and seas are charged with sediment, varying in quantity, composition, colour, and grain according to the seasons; the waters are sometimes flooded and rapid, at other periods low and feeble; different tributaries, also, draining peculiar countries and soils, and therefore charged with peculiar sediment, are swollen at distinct periods. It was also shown that the waves of the sea and currents undermine the cliffs during wintry storms, and sweep away the materials into the deep, after which a season of tranquillity succeeds, when nothing but the finest mud is spread by the movements of the ocean over the same submarine area.

It is not the object of the present work to give a description of these operations, repeated as they are, year after year, and century after century; but I may suggest an explanation of the manner in which some micaceous sandstones have originated, namely, those in which we see innumerable thin layers of mica dividing layers of fine quartzose sand. I observed the same arrangement of materials in recent mud deposited in the estuary of La Roche St. Bernard in Brittany, at the mouth of the Loire. The surrounding rocks are of gneiss, which, by its waste, supplies the mud: when this dries at low water, it is found to consist of brown laminated clay, divided by thin seams of mica. The separation of the mica in this case, or in that of micaceous sandstones, may be thus understood. If we take a handful of quartzose sand, mixed with mica, and throw it into a clear running stream, we see the materials immediately sorted by the water, the grains of quartz falling almost directly to the bottom, while the plates of mica take a much longer time to reach the bottom, and are carried farther down the stream. At the first instant the water is turbid, but immediately after the flat surfaces of the plates of mica are seen all alone reflecting a silvery light, as they descend slowly, to form a distinct micaceous lamina. The mica is the heavier mineral of the two; but it remains a longer time suspended in the fluid, owing to its greater extent of surface. It is easy, therefore, to perceive that where such mud is acted upon by a river or tidal current, the thin plates of mica will be carried farther, and not deposited in the same places as the grains of quartz; and since the force and velocity of the stream varies from time to time, layers of mica or of sand will be thrown down successively on the same area.

Original horizontality.—It is said generally that the upper and

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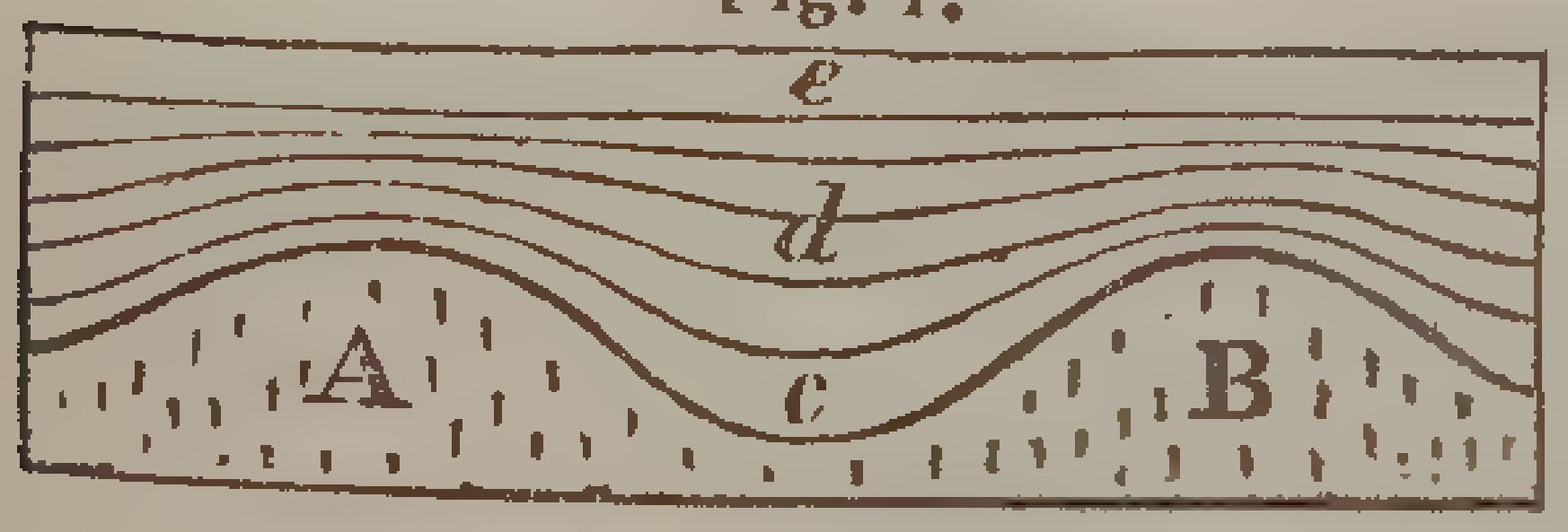
* Consult Index to Principles of Geology, "Stratification," "Currents," "Deltas," "Water," &c.

under surfaces of strata, or the "planes of stratification," are parallel. Although this is not strictly true, they make an approach to parallelism, for the same reason that sediment is usually deposited at first in nearly horizontal layers. The reason of this arrangement can by no means be attributed to an original evenness or horizontality in the bed of the sea: for it is ascertained that in those places where no matter has been recently deposited, the bottom of the ocean is often as uneven as that of the dry land, having in like manner its hills, valleys, and ravines. Yet if the sea should sink, or the water be removed near the mouth of a large river where a delta has been forming, we should see extensive plains of mud and sand laid dry, which, to the eye, would appear perfectly level, although, in reality, they would slope gently from the land towards the sea.

This tendency in newly-formed strata to assume a horizontal position arises principally from the motion of the water, which forces along particles of sand or mud at the bottom, and causes them to settle in hollows or depressions where they are less exposed to the force of a current than when they are resting on elevated points. The velocity of the current and the motion of the superficial waves diminish from the surface downwards, and are least in those depressions where the water is deepest.

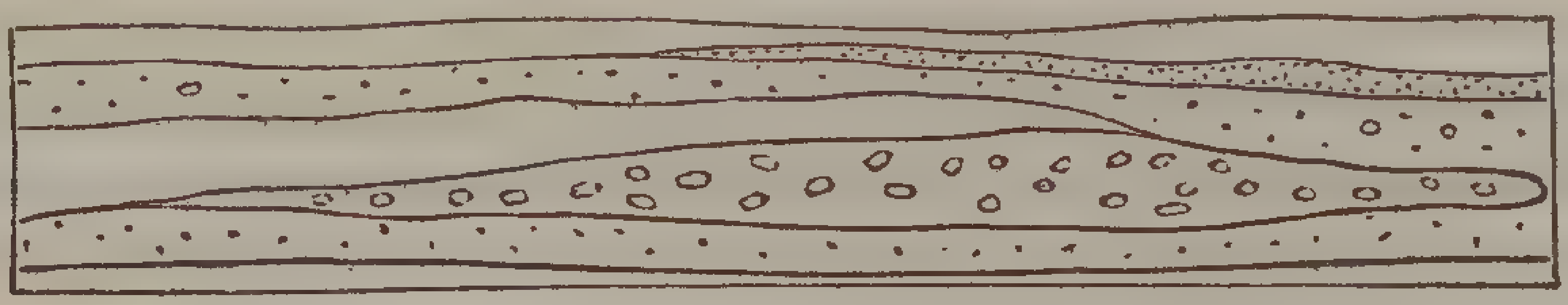
Fig. 1.



A good illustration of the principle here alluded to may be sometimes seen in the neighbourhood of a volcano, when a section, whether natural or artificial, has laid open to view a succession of various-coloured layers of sand and ashes, which have fallen in showers upon uneven ground. Thus let A B (fig. 1.) be two ridges, with an intervening valley. These original inequalities of the surface have been gradually effaced by beds of sand and ashes *c*, *d*, *e*, the surface at *e* being quite level. It will be seen that, although the materials of the first layers have accommodated themselves in a great degree to the shape of the ground A B, yet each bed is thickest at the bottom. At first a great many particles would be carried by their own gravity down the steep sides of A and B, and others would afterwards be blown by the wind as they fell off the ridges, and would settle in the hollow, which would thus become more and more effaced as the strata accumulated from *c* to *e*. This levelling operation may perhaps be rendered more clear to the student by supposing a number of parallel trenches to be dug in a plain of moving sand, like the African desert, in which case the wind would soon cause all signs of these trenches to disappear, and the surface would be as uniform as before. Now, water in motion can exert this levelling power on similar materials more easily than air, for almost all stones lose in water more than a third of the weight which they have in air, the specific gravity of rocks being in general as 2½ when compared to that of water, which is estimated at 1. But the buoyancy of sand or mud would be still greater in the sea, as the density of salt water exceeds that of fresh.

Yet, however uniform and horizontal may be the surface of new deposits in general, there are still many disturbing causes, such as eddies in the water, and currents moving first in one and then in another direction, which frequently cause irregularities. We may sometimes follow a bed of limestone, shale, or sandstone, for a distance of many hundred yards continuously; but we generally find at length that each individual stratum thins out, and allows the beds which were previously above and below it to meet. If the materials are coarse, as in grits and conglomerates, the same beds can rarely be traced many yards without varying in size, and often coming to an end abruptly. (See fig. 2.)

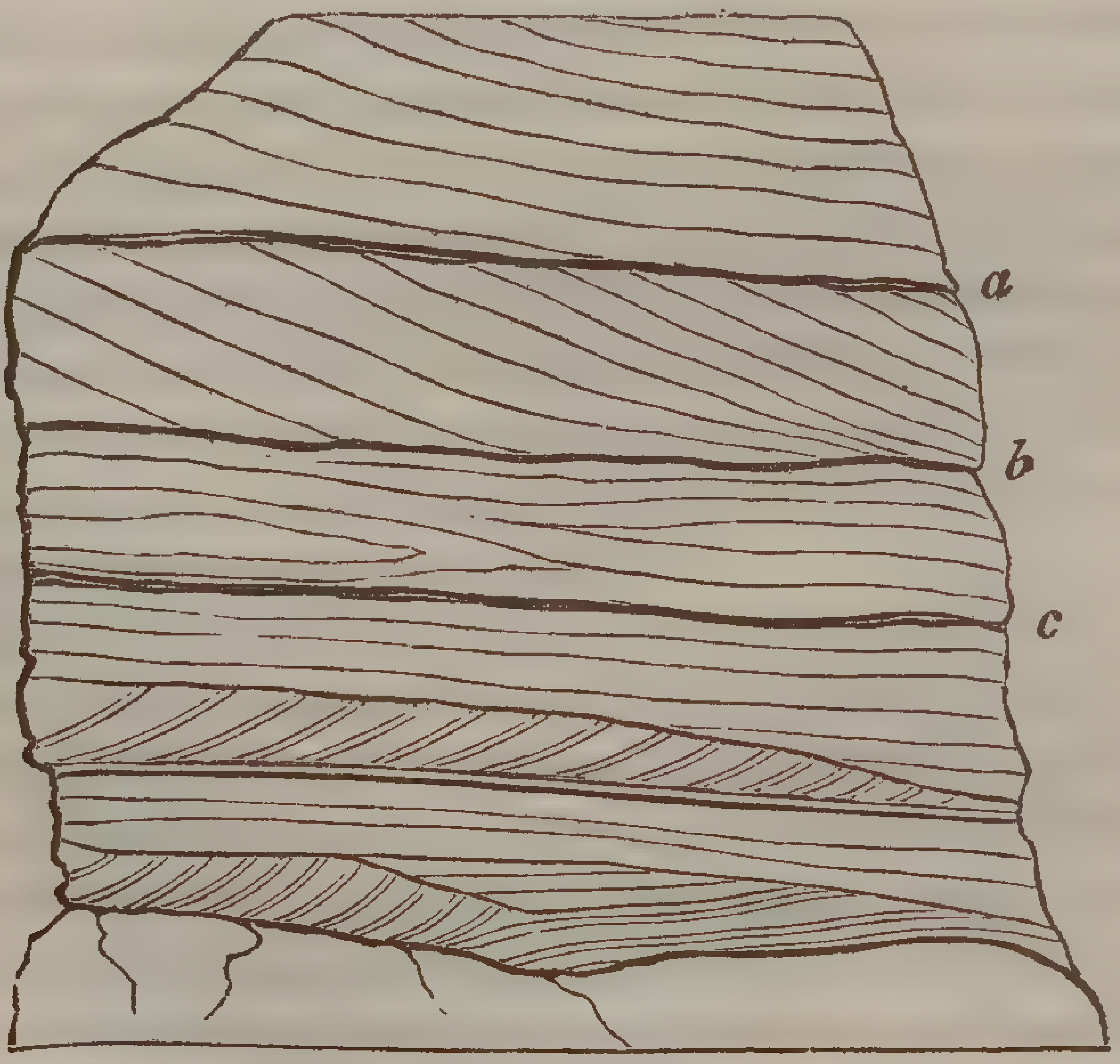
Fig. 2.



Section of strata of sandstone, grit, and conglomerate.

Diagonal or cross stratification.—There is also another phenomenon of frequent occurrence. We find a series of larger strata, each of which is composed of a number of minor layers placed obliquely to the general planes of stratification. To this diagonal arrangement the name of "false or cross stratification" has been given. Thus in the annexed section (fig. 3.) we see seven or eight large beds of loose sand, yellow and brown, and the lines *a*, *b*, *c*, mark some of the principal planes of stratification, which are nearly horizontal. But the greater part of the subordinate laminæ do not conform to these planes, but have often a steep slope, the inclination being sometimes towards opposite points of the compass. When the sand is loose and incoherent, as in the case here represented, the

Fig. 3.



Section of sand at Sandy Hill, near Biggleswade, Bedfordshire.
Height 20 feet. (Green-sand formation.)

deviation from parallelism of the slanting laminæ cannot possibly be accounted for by any re-arrangement of the particles acquired during the consolidation of the rock. In what manner then can such irregularities be due to original deposition? We must suppose that at the bottom of the sea, as well as in the beds of rivers, the motions of waves, currents, and eddies often cause mud, sand, and gravel to be thrown down in heaps on particular spots instead of being spread out uniformly over a wide area. Sometimes, when banks are thus formed, currents may cut passages through them, just as a river forms its bed. Suppose the bank A (fig. 4.) to be thus formed with a steep sloping side, and the water being in a tranquil state, the layer of sediment No. 1. is thrown down upon it, conforming nearly to its surface. Afterwards the other layers, 2, 3, 4, may be deposited in succession, so that the bank B C D is formed. If the current then increases in velocity, it may cut away the upper portion of this mass down to the dotted line *e* (fig. 4.), and deposit the materials thus removed farther on, so as to form the layers 5, 6, 7, 8. We have now the bank B C D E (fig. 5.), of which the surface is almost level and on which the nearly horizontal layers, 9, 10, 11, may then accumulate. It was shown in fig. 3. that the diagonal layers of successive strata may sometimes have an opposite slope. This is well seen in some cliffs of loose sand on the Suffolk coast. A portion of one of these is represented in fig. 6., where the layers, of which there are about six in the thickness of an inch, are composed of quartzose grains. This arrangement may have been due to the altered direction of the tides and currents in the same place.

Fig. 4.

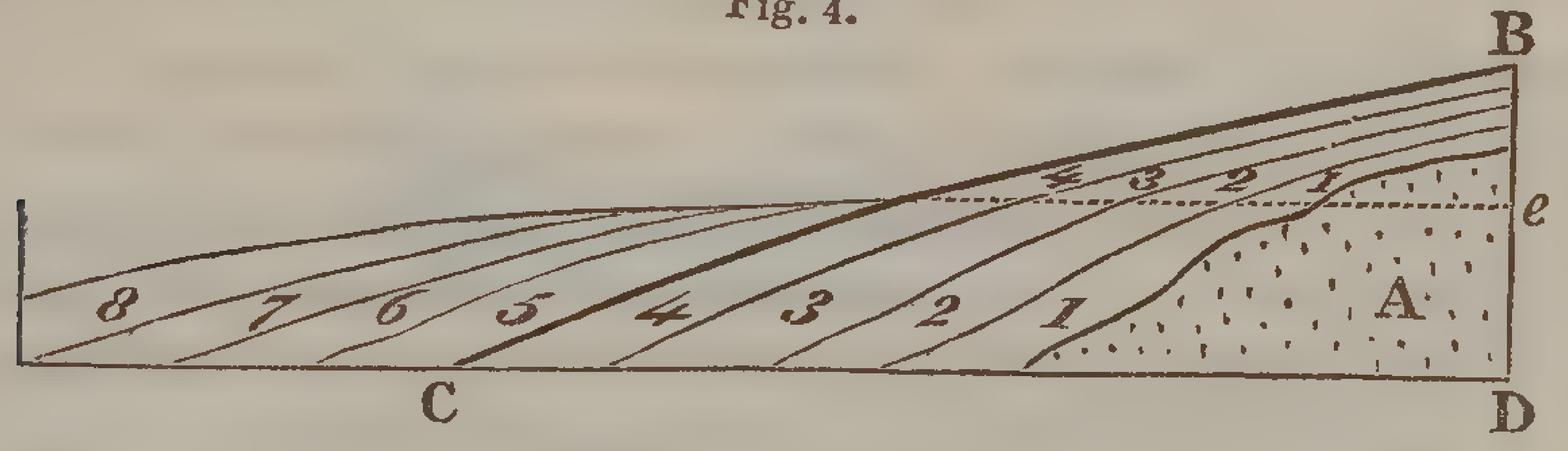


Fig. 5.

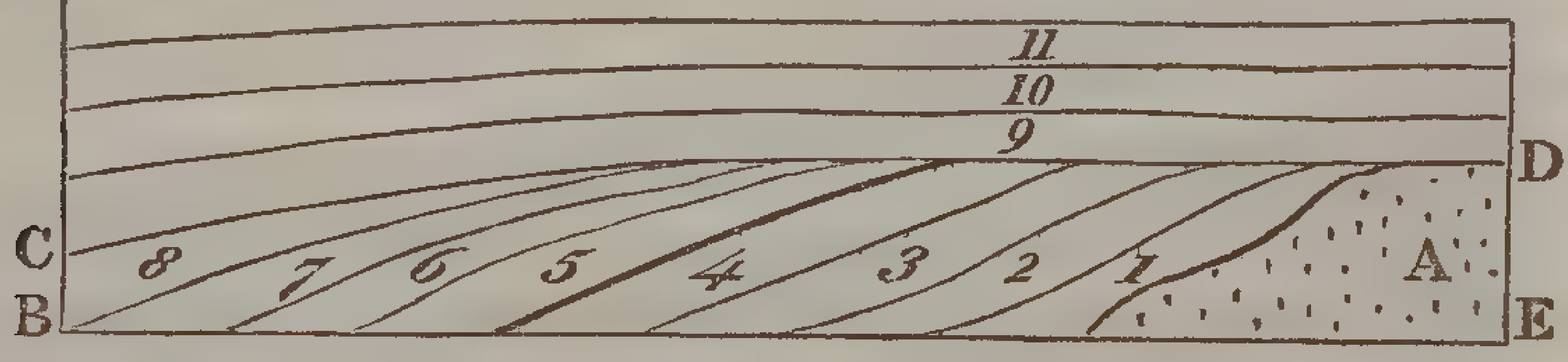
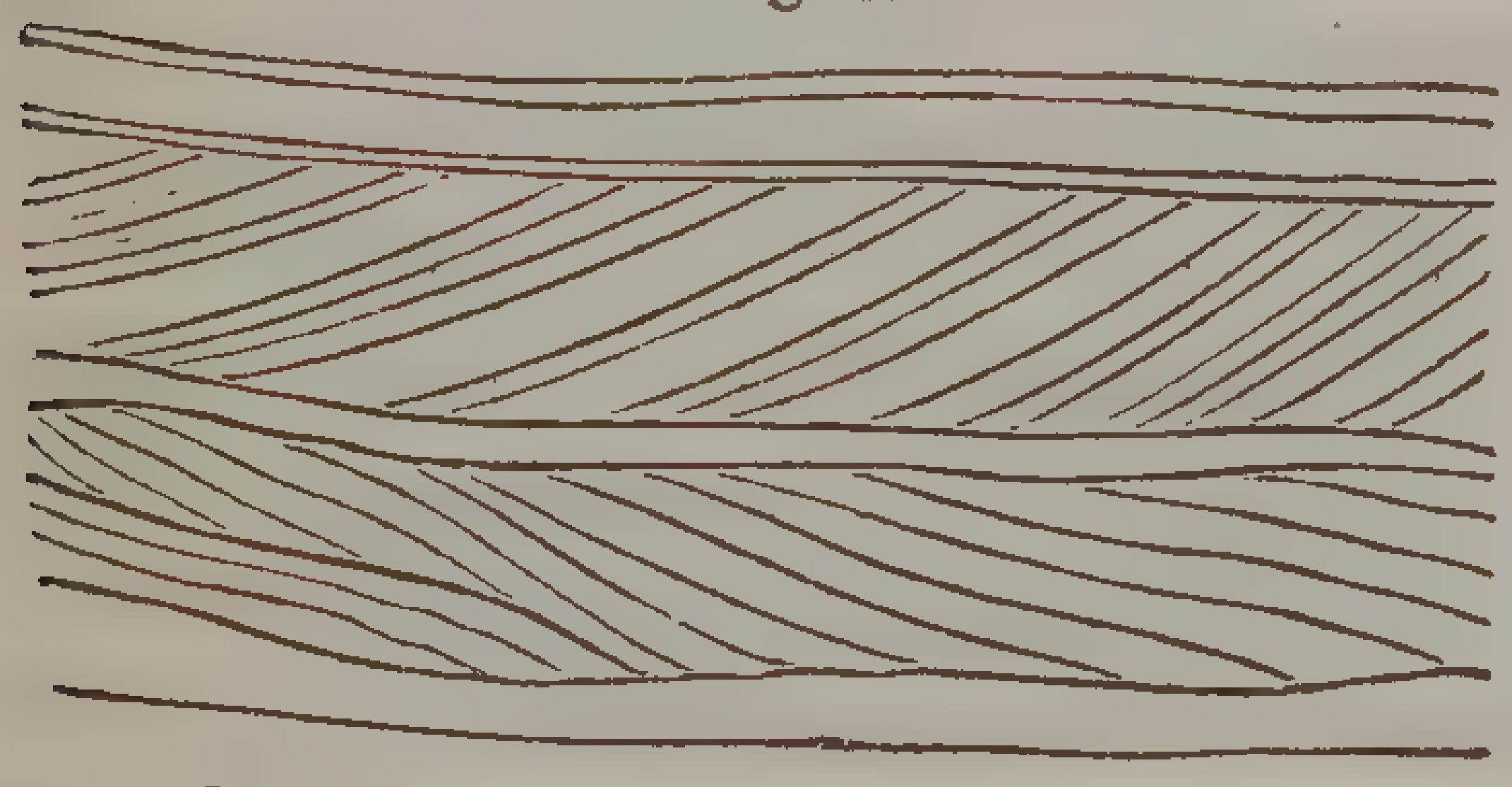


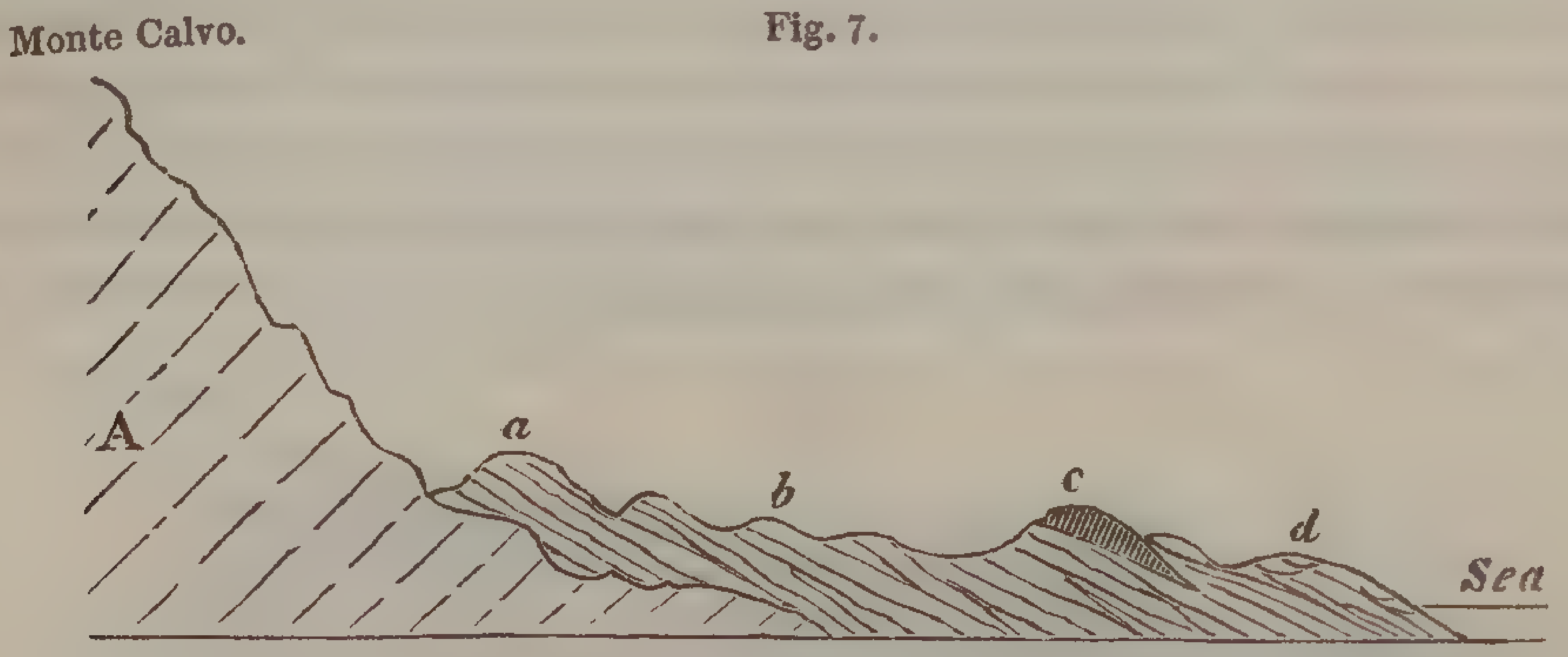
Fig. 6.



Cliff between Mismer and Dunwich.

The description above given of the slanting position of the minor layers constituting a single stratum is in certain cases applicable on a much grander scale to masses several hundred feet thick, and many miles in extent. A fine example may be seen at the base of the Maritime Alps near Nice. The mountains here terminate abruptly in the sea, so that a depth of many hundred fathoms is often found within a stone's throw of the beach, and sometimes a depth of 3000 feet within half a mile. But at certain points, strata of sand, marl, or conglomerate, intervene between the shore and the mountains, as in the annexed fig. (7.), where a vast succession of slanting beds of gravel and sand may be traced from the sea to Monte Calvo, a distance of no less than 9 miles in a straight line. The dip of these beds is remarkably uniform, being always southward or towards the Mediterranean, at an angle of about 25°. They are exposed to view in nearly vertical precipices, varying from 200 to 600 feet in height, which bound the valley through which the river Magnan flows. Although, in a general view, the strata appear to be parallel and uniform, they are nevertheless found, when examined closely, to be wedge-shaped, and to thin out when followed for a few hundred feet or yards, so that we may suppose them to have been thrown down originally upon the side of a steep bank where a river or alpine torrent discharged itself into a deep and tranquil sea, and formed a delta, which advanced gradually from the base of Monte Calvo to a distance of 9 miles from the original shore. If subsequently this part of the Alps and bed of the sea were raised 700 feet, the coast would acquire its present configuration, the delta would emerge, and a deep channel might then be cut through it by a river.

Fig. 7.



Section from Monte Calvo to the sea by the valley of Magnan, near Nice.

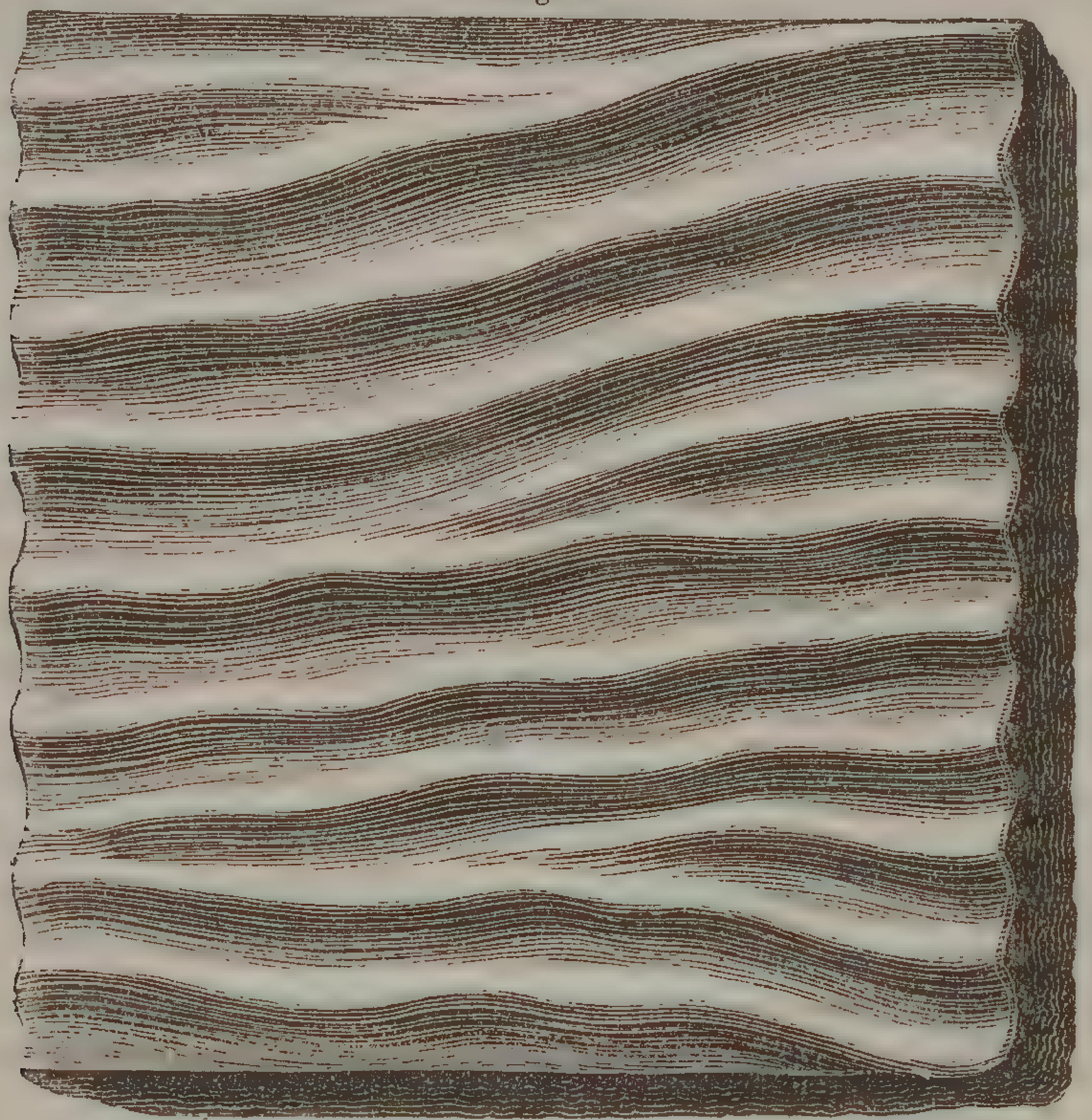
A. Dolomite and sandstone. (Green-sand formation?)
a, b, d. Beds of gravel and sand.
c. Fine marl and sand of St. Madeleine, with marine shells.

It is well known that the torrents and streams, which now descend from the alpine declivities to the shore, bring down annually, when the snow melts, vast quantities of shingle and sand, and then, as they subside, fine mud, while in summer they are nearly or entirely dry; so that it may be safely assumed, that deposits like those of the valley of the Magnan, consisting of coarse gravel alternating with fine sediment, are still in progress at many points, as, for instance, at the mouth of the Var. They must advance upon the Mediterranean in the form of great shoals terminating in a steep talus; such being the original mode of accumulation of all coarse materials conveyed into deep water, especially where they are composed in great part of pebbles, which cannot be transported to indefinite distances by currents of moderate velocity. By inattention to facts and inferences of this kind, a very exaggerated estimate has sometimes been made of the supposed depth of the ancient ocean. There can be no doubt, for example, that the strata *a*, fig. 7., or those nearest to Monte Calvo, are older than those indicated by *b*, and these again were formed before *c*; but the vertical depth of gravel and sand in any one place cannot be proved to amount even to 1000 feet, although it may perhaps be much greater, yet probably never exceeding at any point 3000 or 4000 feet. But were we to assume that all the strata were once horizontal, and that their present dip or inclination was due to subsequent movements, we should then be forced to conclude, that a sea 9 miles deep had been filled up with alternate layers of mud and pebbles thrown down one upon another.

In the locality now under consideration, situated a few miles to the west of Nice, there are many geological data, the details of which cannot be given in this place, all leading to the opinion, that when the deposit of the Magnan was formed, the shape and outline of the alpine declivities and the shore greatly resembled what we now behold at many points in the neighbourhood. That the beds, *a*, *b*, *c*, *d*, are of comparatively modern date is proved by this fact, that in seams of loamy marl intervening between the pebbly beds are fossil shells, half of which belong to species now living in the Mediterranean.

Ripple mark.—The ripple mark, so common on the surface of sandstones of all ages (see fig. 8.), and which is so often seen on the sea-shore at low tide, seems to originate in the drifting of materials along the bottom of the water, in a manner very similar to that which may explain the inclined layers above described. This ripple is not entirely confined to the beach between high and low water mark, but is also produced on sands which are constantly covered by water.

Fig. 8.



Slab of ripple-marked (new red) sandstone from Cheshire.

Similar undulating ridges and furrows may also be sometimes seen on the surface of drift snow and blown sand. The following is the manner in which I once observed the motion of the air to produce this effect on a large extent of level beach, exposed at low tide near Calais. Clouds of fine white sand were blown from the neighbouring dunes, so as to cover the shore, and whiten a dark level surface of sandy mud, and this fresh covering of sand was beautifully rippled. On levelling all the small ridges and furrows of this ripple over an area of several yards square, I saw them perfectly restored in about ten minutes, the general direction of the ridges being always at right angles to that of the wind. The restoration began by the appearance here and there of small detached heaps of sand, which soon lengthened and joined together, so as to form long sinuous ridges with intervening furrows. Each ridge had one side slightly inclined, and the other steep; the lee-side being always steep, as *b, c,*—*d, e;* the windward-side a gentle slope, as *a, b,*—*c, d,* fig. 9. When a gust of wind blew with sufficient force to drive along a cloud of sand, all the ridges were seen to be in motion at once, each encroaching on the furrow before it, and, in the course of a few minutes, filling the place which the furrows had occupied. The mode of advance was by the continual drifting of grains of sand up the slopes *a b* and *c d,* many of which grains, when they arrived at *b* and *d,* fell over the scarps *b c* and *d e,* and were under shelter from the wind; so that they remained stationary, resting, according to their shape and momentum, on different parts of the descent, and a few only rolling to the bottom. In this manner each ridge was distinctly seen to move slowly on as often as the force of the wind augmented. Occasionally part of a ridge, advancing more rapidly than the rest, overtook the ridge immediately before it, and became confounded with it, thus causing those bifurcations and branches which are so common, and two of which are seen in the slab, fig. 8. We may observe this configuration in sandstones of all ages, and in them also, as now on the sea-coast, we may often detect two systems of ripples interfering with each other; one more ancient and half effaced, and a newer one, in which the grooves and ridges are more distinct, and in a different direction. This crossing of two sets of ripples arises from a change of wind, and the new direction in which the waves are thrown on the shore.

Fig. 9.

The ripple mark is usually an indication of a sea-beach, or of water from 6 to 10 feet deep, for the agitation caused by waves even during storms extends to a very slight depth. To this rule, however, there are some exceptions, and recent ripple marks have been observed at the depth of 60 or 70 feet. It has also been ascertained that currents or large bodies of water in motion may disturb mud and sand at the depth of 300 or even 450 feet.* Beach ripple, however, may usually be distinguished from current ripple by frequent changes in its direction. In a slab of sandstone, not more than an inch thick, the furrows or ridges of an ancient ripple may often be seen in several successive laminæ to run towards different points of the compass.

CHAPTER III.

ARRANGEMENT OF FOSSILS IN STRATA — FRESHWATER AND MARINE.

Successive deposition indicated by fossils — Limestones formed of corals and shells — Proofs of gradual increase of strata derived from fossils — Serpula attached to spatangus — Wood bored by teredina — Tripoli and semi-opal formed of infusoria — Chalk derived principally from organic bodies—Distinction of freshwater from marine formations — Genera of freshwater and land shells — Rules for recognizing marine testacea — Gyrogonite and chara — Freshwater fishes — Alternation of marine and freshwater deposits — Lym-Fiord.

HAVING in the last chapter considered the forms of stratification so far as they are determined by the arrangement of inorganic matter, we may now turn our attention to the manner in which organic remains are distributed through stratified deposits. We should often be unable to detect any signs of stratification or of successive deposition, if particular kinds of fossils did not occur here and there at certain depths in the mass. At one level, for example, univalve shells of some one or more species predominate; at another, bivalve shells; and at a third, corals; while in some formations we find layers of vegetable matter, commonly derived from land plants, separating strata.

It may appear inconceivable to a beginner how mountains, several thousand feet thick, can have become filled with fossils from top to bottom; but the difficulty is removed, when he reflects on the origin of stratification, as explained in the last chapter, and allows sufficient time for the accumulation of sediment. He must never lose sight of the fact that, during the process of deposition, each separate layer was once the uppermost, and covered immediately by the water in which aquatic animals lived. Each stratum in fact, however far it may now lie beneath the surface, was once in the state of shingle, or loose sand or soft mud at the bottom of the sea, in which shells and other bodies easily became enveloped.

By attending to the nature of these remains, we are often enabled to determine whether the deposition was slow or rapid, whether it took place in a deep or shallow sea, near the shore or far from land, and whether the water was salt, brackish, or fresh. Some limestones consist almost exclusively of corals, and in many cases it is evident

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* Edin. New Phil. Journ. vol. xxxi.; and Darwin, Volc. Islands, p. 134.

that the present position of each fossil zoophyte has been determined by the manner in which it grew originally. The axis of the coral, for example, if its natural growth is erect, still remains at right angles to the plane of stratification. If the stratum be now horizontal, the round spherical heads of certain species continue uppermost, and their points of attachment are directed downwards. This arrangement is sometimes repeated throughout a great succession of strata. From what we know of the growth of similar zoophytes in modern reefs, we infer that the rate of increase was extremely slow, and some of the fossils must have flourished for ages like forest trees, before they attained so large a size. During these ages, the water remained clear and transparent, for such corals cannot live in turbid water.

In like manner, when we see thousands of full-grown shells dispersed every where throughout a long series of strata, we cannot doubt that time was required for the multiplication of successive generations; and the evidence of slow accumulation is rendered more striking from the proofs, so often discovered, of fossil bodies having lain for a time on the floor of the ocean after death before they were imbedded in sediment. Nothing, for example, is more common than to see fossil oysters in clay, with serpulæ, or barnacles (acorn-shells), or corals, and other creatures, attached to the inside of the valves, so that the mollusk was certainly not buried in argillaceous mud the moment it died. There must have been an interval during which it was still surrounded with clear water, when the creatures whose remains now adhere to it, grew from an embryo to a mature state. Attached shells which are merely external, like some of the serpulæ (*a*) in the annexed figure (fig. 10.), may often have grown upon an oyster or other shell while the animal within was still living; but if they are found on the inside, it could only happen after the death of the inhabitant of the shell which affords the support. Thus, in fig. 10., it will be seen that two serpulæ have grown on the interior, one of them exactly on the place where the adductor muscle of the *Gryphæa* (a kind of oyster) was fixed.

Fig. 10.

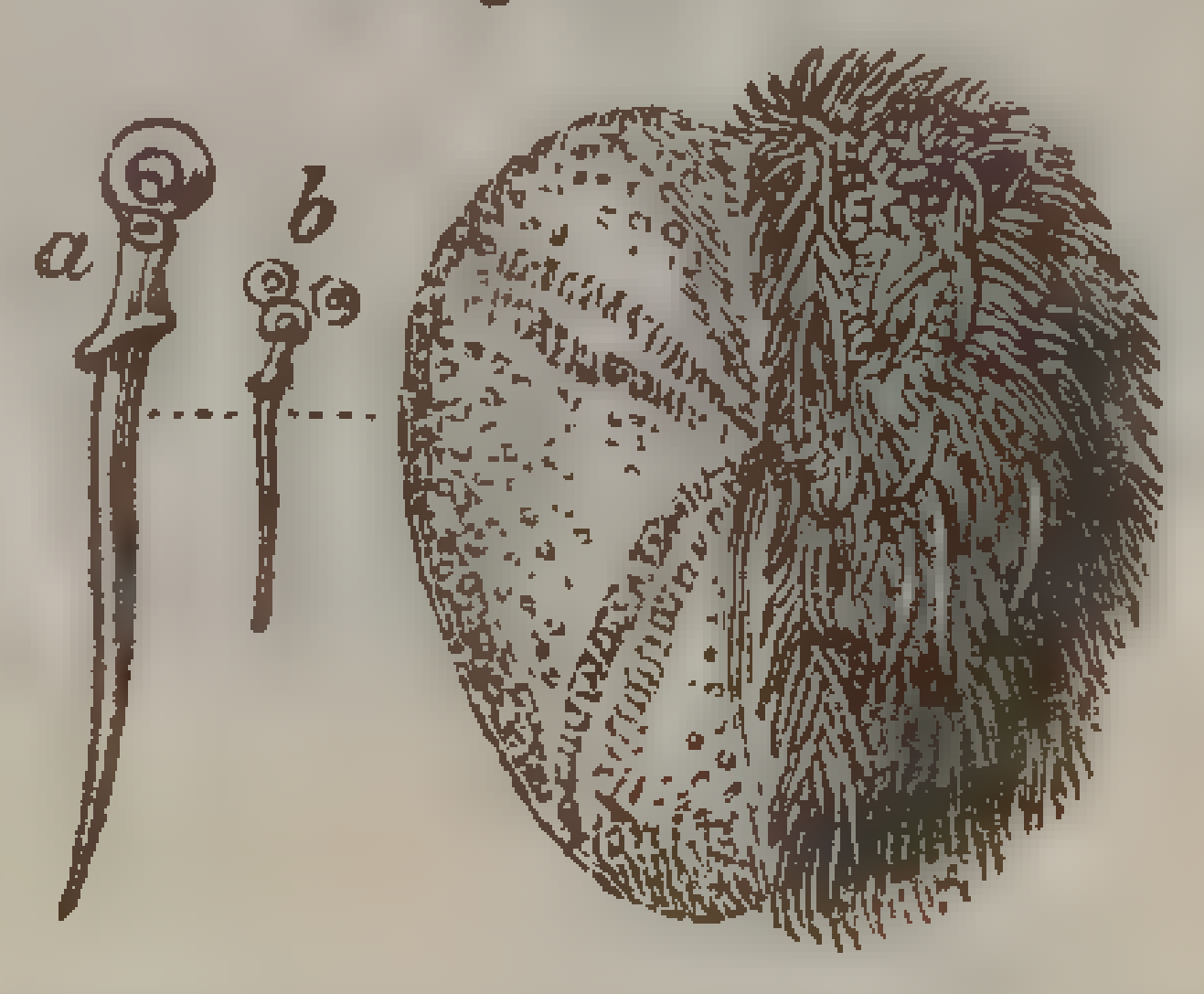
Fossil *Gryphæa*, covered both on the outside and inside with fossil serpulæ.

Some fossil shells, even if simply attached to the *outside* of others, bear full testimony to the conclusion above alluded to, namely, that an interval elapsed between the death of the creature to whose shell they adhere, and the burial of the same in mud or sand. The sea-urchins or *Echini*, so abundant in white chalk, afford a good illustration. It is well known that these animals, when living, are invariably covered with numerous suckers, or gelatinous tubes, called "ambulacral," because they serve as organs of motion. They are also armed with spines supported by rows of tubercles. These last are only seen after the death of the sea-urchin, when the spines have dropped off. In fig. 12. a living species of *Spatangus*, common on our coast, is represented with one half of its shell stripped of the spines. In fig. 11. a fossil of the same genus from the white chalk of England shows the naked surface which the individuals of this family exhibit when denuded of their bristles. The full-grown *Serpula*, therefore, which now adheres externally, could not have begun to grow till the *Spatangus* had died, and the spines were detached.

Fig. 11.

Serpula attached to a fossil *Spatangus* from the chalk.

Fig. 12.



Recent *Spatangus* with the spines removed from one side.

b. Spine and tubercles, nat. size.
a. The same magnified.

Now the series of events here attested by a single fossil may be carried a step farther. Thus, for example, we often meet with a sea-urchin in the chalk (see fig. 13.), which has fixed to it the lower valve of a *Crania*, a genus of bivalve mollusca. The upper valve (*b*, fig. 13.) is almost invariably wanting, though occasionally found in a perfect state of preservation in white chalk at some distance. In this case, we see clearly that the sea-urchin first lived from youth to age, then died and lost its spines, which were carried away. Then the young *Crania* adhered to the bared shell, grew and perished in its turn; after which the upper valve was separated from the lower before the *Echinus* became enveloped in chalky mud.

Fig. 13.

a. *Echinus* from the chalk with lower valve of the *Crania* attached.
b. Upper valve of the *Crania* detached.

It may be well to mention one more illustration of the manner in which single fossils may sometimes throw light on a former state of things, both in the bed of the ocean and on some adjoining land. We meet with many fragments of wood bored by ship-worms at various depths in the clay on which London is built. Entire branches and stems of trees, several feet in length, are sometimes dug out, drilled all over by the holes of these borers, the tubes and shells of the mollusk still remaining in the cylindrical hollows. In fig. 15. *e*, a representation is given of a piece of recent wood pierced by the *Teredo navalis*, or common ship-worm, which destroys wooden piles and ships. When the cylindrical tube *d* has been extracted from the wood, a shell is seen at the larger extremity, composed of two pieces, as shown at *c*. In like manner, a piece of fossil wood (*a*, fig. 14.)

has been perforated by an animal of a kindred but extinct genus, called *Teredina* by Lamarck. The calcareous tube of this mollusk was united and as it were soldered on to the valves of the shell (*b*), which therefore cannot be detached from the tube, like the valves of the recent *Teredo*. The wood in this fossil specimen is now converted into a stony mass, a mixture of clay and lime; but it must once have been buoyant and floating in the sea, when the *Teredinæ* lived upon it, perforating it in all directions. Again, before the infant colony settled upon the drift wood, the branch of a tree must have been floated down to the sea by a river, uprooted, perhaps, by a flood, or torn off and cast into the waves by the wind: and thus our thoughts are carried back to a prior period, when the tree grew for years on dry land, enjoying a fit soil and climate.

Fig. 14.

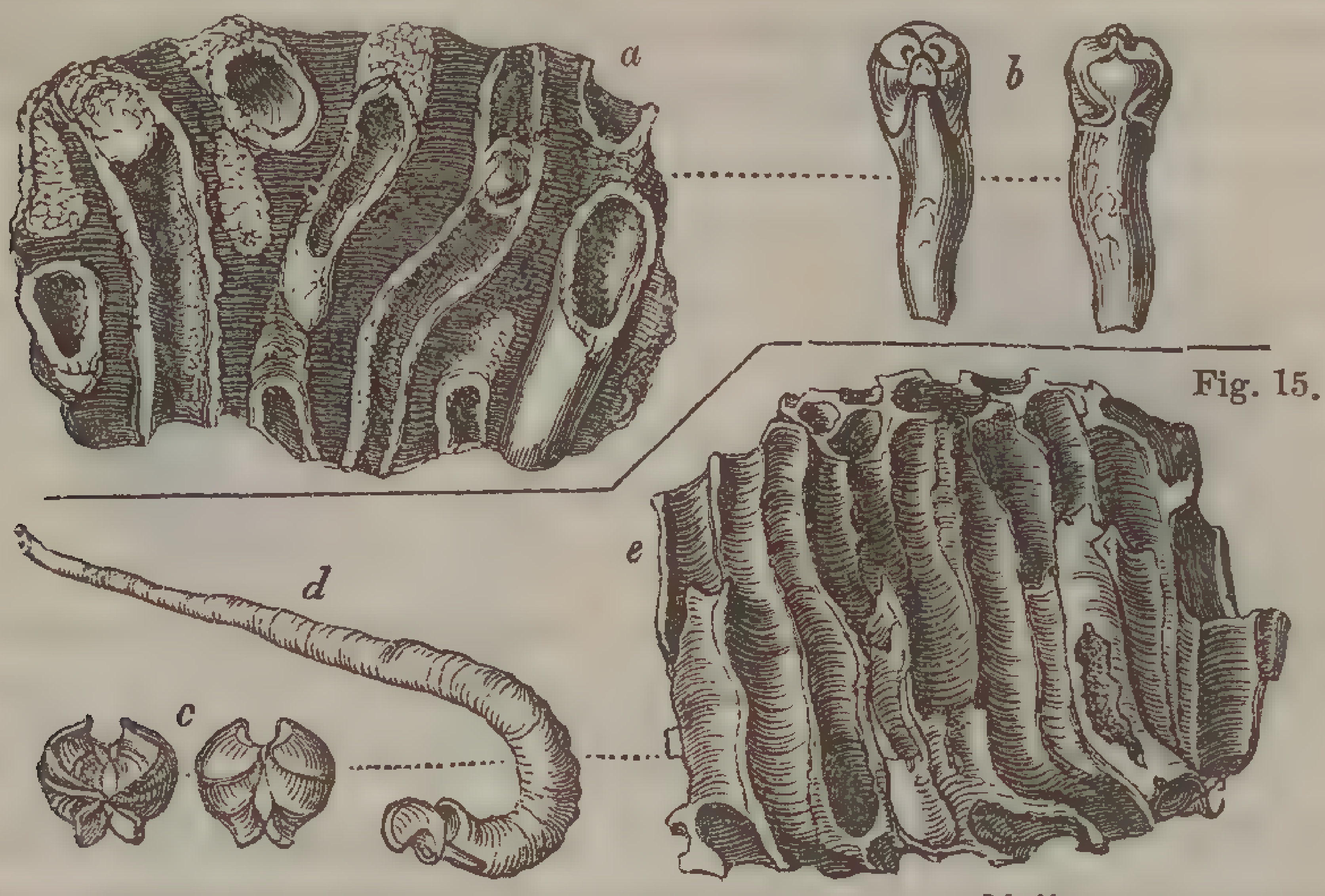


Fig. 15.

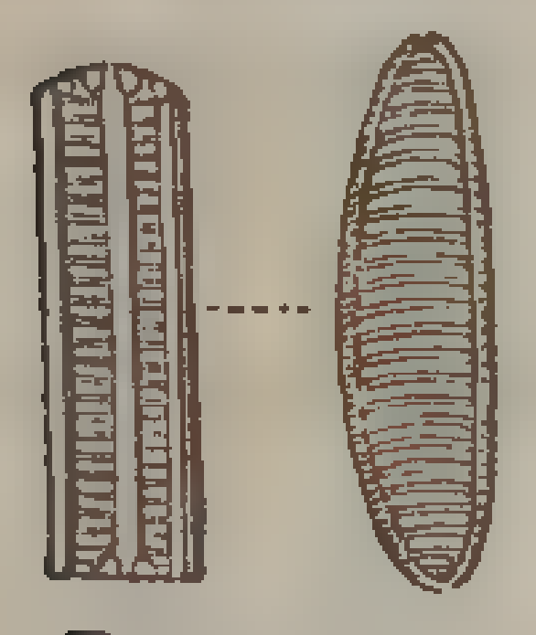
Fossil and recent wood drilled by perforating Mollusca.

Fig. 14. *a*. Fossil wood from London clay, bored by *Teredina*.
b. Shell and tube of *Teredina personata*, the right-hand figure the ventral, the left the dorsal view.

Fig. 15. *e*. Recent wood bored by *Teredo*.
d. Shell and tube of *Teredo navalis*, from the same.
c. Anterior and posterior view of the valves of same detached from the tube.

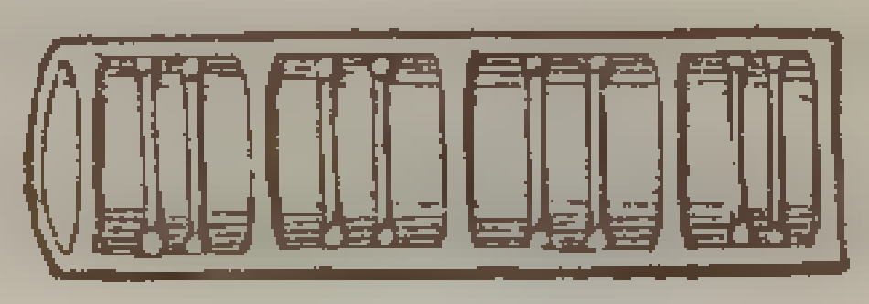
It has been already remarked that there are rocks in the interior of continents, at various depths in the earth, and at great heights above the sea, almost entirely made up of the remains of zoophytes and testacea. Such masses may be compared to modern oyster-beds and coral-reefs; and, like them, the rate of increase must have been extremely gradual. But there are a variety of stony deposits in the earth's crust, now proved to have been derived from plants and animals of which the organic origin was not suspected until of late years, even by naturalists. Great surprise was therefore created by the recent discovery of Professor Ehrenberg, of Berlin, that a certain kind of siliceous stone, called tripoli, was entirely composed of millions of the remains of organic beings, which the Prussian naturalist refers to microscopic Infusoria, but which most others now believe to be plants. They abound in freshwater lakes and ponds in England and other countries, and are termed Diatomaceæ by those naturalists who believe in their vegetable origin. The substance alluded to has long been well known in the arts, being used in the form of powder for polishing stones and metals. It has been procured, among other places, from Bilin, in Bohemia, where a single stratum, extending over a wide area, is no less than 14 feet thick. This stone, when examined with a powerful microscope, is found to consist of the siliceous plates or frustules of the above-mentioned Diatomaceæ, united together without any visible cement. It is difficult to convey an idea of their extreme minuteness; but Ehrenberg estimates that in the Bilin tripoli there are 41,000 millions of individuals of the *Gaillonella distans* (see fig. 17.) in every cubic inch, which weighs about 220 grains, or about 187 millions in a single grain. At every stroke, therefore, that we make with this polishing powder, several millions, perhaps tens of millions, of perfect fossils are crushed to atoms.

Fig. 16.



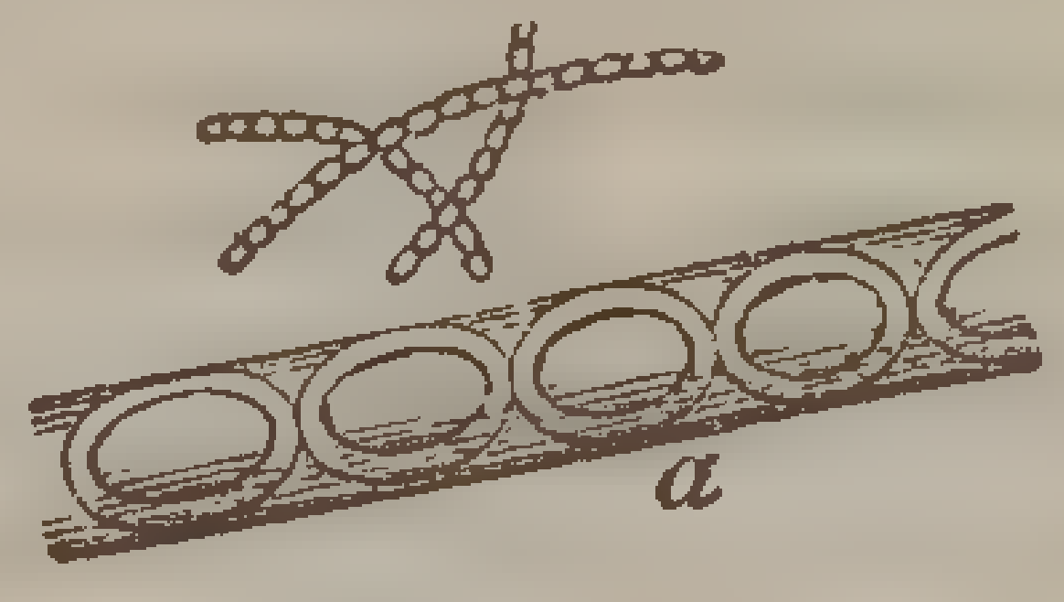
Bacillaria vulgaris?

Fig. 17.



Gaillonella distans.

Fig. 18.



Gaillonella ferruginea.

These figures are magnified nearly 300 times, except the lower figure of *G. ferruginea* (fig. 18. *a*), which is magnified 2000 times.

Fig. 20. Fig. 19.

Fragment of semi-opal from the great bed of tripoli, Bilin.

Fig. 19. Natural size.
Fig. 20. The same magnified, showing circular articulations of a species of *Gaillonella*, and spiculæ of *Spongilla*.

The remains of these Diatomaceæ are of pure silex, and their forms are various, but very marked and constant in particular genera and species. Thus, in the family *Bacillaria* (see fig. 16.), the fossils preserved in tripoli are seen to exhibit the same divisions and transverse lines which characterize the living species of kindred form. With these, also, the siliceous spiculæ or internal supports of the freshwater sponge, or *Spongilla* of Lamarck, are sometimes intermingled (see the needle-shaped bodies in fig. 20.). These flinty cases and spiculæ, although hard, are very fragile, breaking like glass, and are therefore admirably adapted, when rubbed, for wearing down into a fine powder fit for polishing the surface of metals.

Besides the tripoli, formed exclusively of the fossils above described, there occurs in the upper part of the great stratum at Bilin another heavier and more compact stone, a kind of semi-opal, in which innumerable parts of Diatomaceæ and spiculæ of the *Spongilla* are filled with, and cemented together by, siliceous matter. It is supposed that the siliceous remains of the most delicate Diatomaceæ have been dissolved by water, and have thus given rise to this opal in which the more durable fossils are preserved like insects in amber. This opinion is confirmed by the fact that the organic bodies decrease in number and sharpness of outline in proportion as the opaline cement increases in quantity.

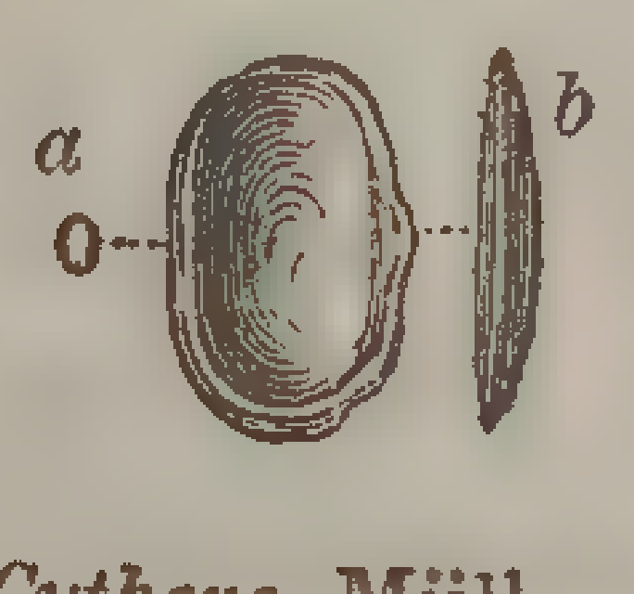
In the Bohemian tripoli above described, as in that of Planitz in Saxony, the species of Diatomaceæ (or Infusoria, as termed by Ehrenberg) are freshwater; but in other countries, as in the tripoli of the Isle of France, they are of marine species, and they all belong to formations of the *tertiary* period, which will be spoken of hereafter.

A well-known substance, called bog-iron ore, often met with in peat-mosses, has also been shown by Ehrenberg to consist of innumerable articulated threads, of a yellow ochre colour, composed partly of flint and partly of oxide of iron. These threads are the cases of a minute microscopic body, called *Gaillonella ferruginea* (fig. 18.).

It is clear that much time must have been required for the accumulation of strata to which countless generations of Diatomaceæ have contributed their remains; and these discoveries lead us naturally to suspect that other deposits, of which the materials have usually been supposed to be inorganic, may in reality have been derived from microscopic organic bodies. That this is the case with the white chalk, has often been imagined, this rock having been observed to abound in a variety of marine fossils, such as echini, testacea, bryozoa, corals, sponges, crustacea, and fishes. Mr. Lonsdale, on examining, in Oct. 1835, in the museum of the Geological Society of London, portions of white chalk from different parts of England, found, on carefully pulverizing them in water, that what appear to the eye simply as white grains were, in fact, well preserved fossils. He obtained above a thousand of these from each pound weight of chalk, some being fragments of minute bryozoa and corallines, others entire Foraminifera and Cytheridæ. The annexed drawings will give an idea of the beautiful forms of many of these bodies. The figures *a a* represent their natural size, but, minute as they seem, the smallest of them, such as *a*, fig. 24., are gigantic in comparison with the cases of Diatomaceæ before mentioned. It has, moreover, been lately discovered that the chambers into which these Foraminifera

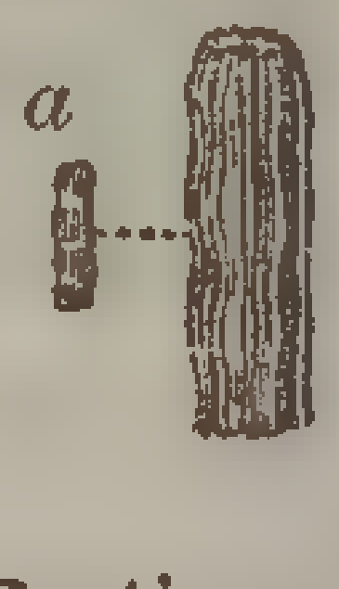
Cytheridæ and *Foraminifera* from the chalk.

Fig. 21.



Cythere, Müll.
Cytherina, Lam.

Fig. 22.



Portion of *Nodosaria*.

Fig. 23.

Cristellaria rotulata.

Fig. 24.

Rosalina.

are divided are actually often filled with thousands of well-preserved organic bodies, which abound in every minute grain of chalk, and are especially apparent in the white coating of flints, often accompanied by innumerable needle-shaped spiculæ of sponges. After reflecting on these discoveries, we are naturally led on to conjecture that, as the formless cement in the semi-opal of Bilin has been derived from the decomposition of animal and vegetable remains, so also many chalk flints in which no organic structure can be recognized may nevertheless have constituted a part of microscopic animalcules.

> "The dust we tread upon was once alive!"—Byron.

How faint an idea does this exclamation of the poet convey of the real wonders of nature! for here we discover proofs that the calcareous and siliceous dust of which hills are composed has not only been once alive, but almost every particle, albeit invisible to the naked eye, still retains the organic structure which, at periods of time incalculably remote, was impressed upon it by the powers of life.

Freshwater and marine fossils.—Strata, whether deposited in salt or fresh water, have the same forms; but the imbedded fossils are very different in the two cases, because the aquatic animals which frequent lakes and rivers are distinct from those inhabiting the sea. In the northern part of the Isle of Wight formations of marl and limestone, more than 50 feet thick, occur, in which the shells are principally, if not all, of extinct species. Yet we recognize their freshwater origin, because they are of the same genera as those now abounding in ponds and lakes, either in our own country or in warmer latitudes.

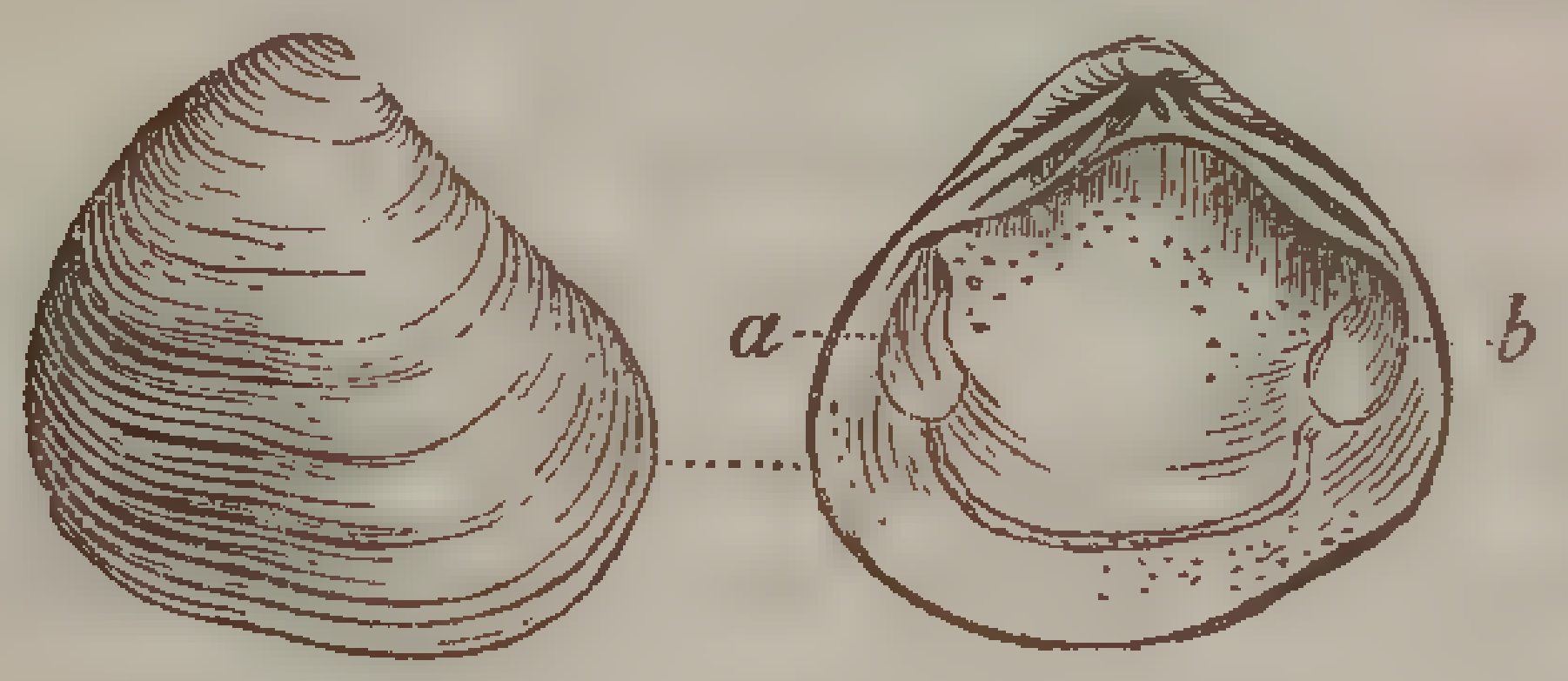
In many parts of France, as in Auvergne, for example, strata of limestone, marl, and sandstone are found, hundreds of feet thick, which contain exclusively freshwater and land shells, together with the remains of terrestrial quadrupeds. The number of land shells scattered through some of these freshwater deposits is exceedingly great; and there are districts in Germany where the rocks scarcely contain any other fossils except snail-shells (*helices*); as, for instance, the limestone on the left bank of the Rhine, between Mayence and Worms, at Oppenheim, Findheim, Budenheim, and other places. In order to account for this phenomenon, the geologist has only to examine the small deltas of torrents which enter the Swiss lakes when the waters are low, such as the newly-formed plain where the Kander enters the Lake of Thun. He there sees sand and mud strewed over with innumerable dead land shells, which have been brought down from valleys in the Alps in the preceding spring, during the melting of the snows. Again, if we search the sands on the borders of the Rhine, in the lower part of its course, we find countless land shells mixed with others of species belonging to lakes, stagnant pools, and marshes. These individuals have been washed away from the alluvial plains of the great river and its tributaries, some from mountainous regions, others from the low country.

Although freshwater formations are often of great thickness, yet they are usually very limited in area when compared to marine deposits, just as lakes and estuaries are of small dimensions in comparison with seas.

We may distinguish a freshwater formation, first, by the absence of many fossils almost invariably met with in marine strata. For example, there are no sea-urchins, no corals, and scarcely any zoophytes; no chambered shells, such as the nautilus, nor microscopic Foraminifera. But it is chiefly by attending to the forms of the mollusca that we are guided in determining the point in question. In a freshwater deposit, the number of individual shells is often as great, if not greater, than in a marine stratum; but there is a smaller variety of species and genera. This might be anticipated from the fact that the genera and species of recent freshwater and land shells are few when contrasted with the marine. Thus, the genera of true mollusca according to Blainville's system, excluding those of extinct species and those without shells, amount to about 200 in number, of which the terrestrial and freshwater genera scarcely form more than a sixth.*

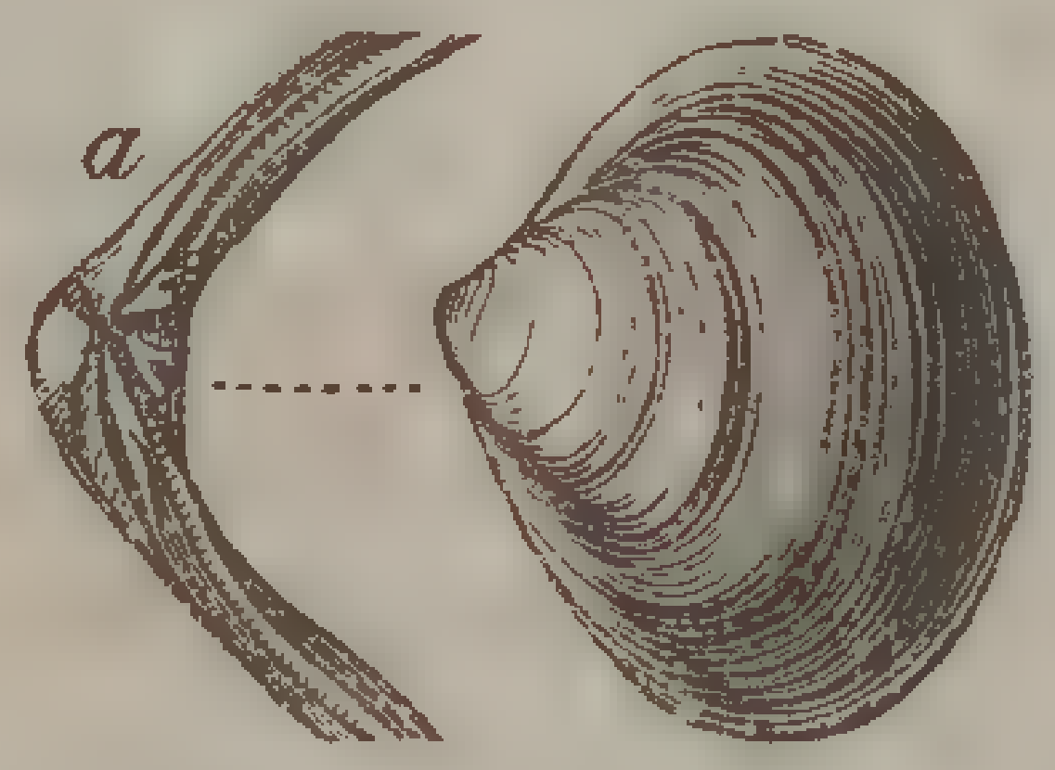
Almost all bivalve shells, or those of acephalous mollusca, are marine, about ten only out of ninety genera being freshwater. Among these last, the four most common forms, both recent and fossil, are *Cyclas*, *Cyrena*, *Unio*, and *Anodonta* (see figures); the two first and two last of which are so nearly allied as to pass into each other.

Fig. 25.



Cyclas obovata; fossil. Hants.

Fig. 26.



Cyrena consobrina; fossil. Grays, Essex.

Fig. 27.

Anodonta Cordierii; fossil. Paris.

Fig. 28.

Anodonta latimarginatus; recent. Bahia.

Fig. 29.

Unio littoralis; recent. Auvergne.

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* See Synoptic Table in Blainville's Malacologie.

Fig. 30.

Gryphæa incurva, Sow. (*G. arcuata*, Lam.) upper valve. Lias.

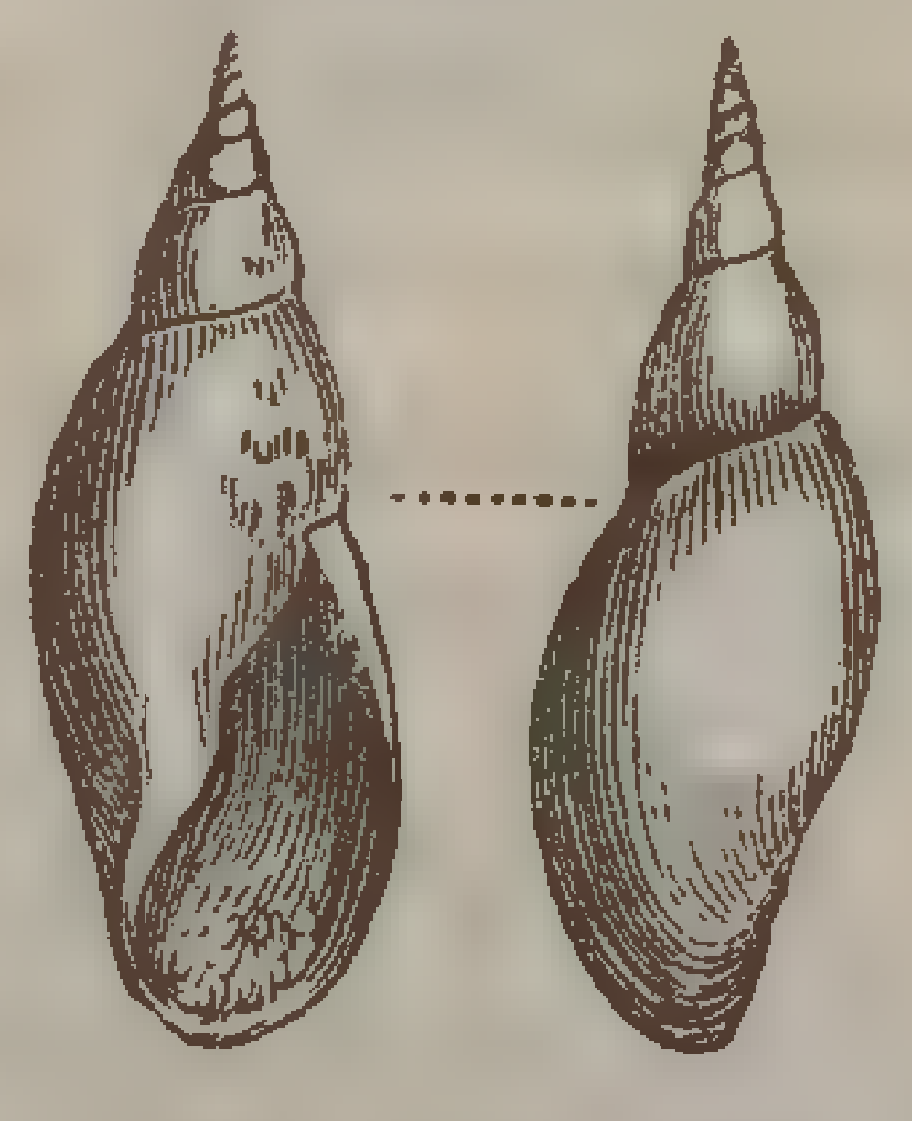
Lamarck divided the bivalve mollusca into the *Dimyary*, or those having two large muscular impressions in each valve, as *a b* in the Cyclas, fig. 25., and the *Monomyary*, such as the oyster and scallop, in which there is only one of these impressions, as is seen in fig. 30. Now, as none of these last, or the unimuscular bivalves, are freshwater, we may at once presume a deposit in which we find any of them to be marine.

The univalve shells most characteristic of fresh-water deposits are, *Planorbis*, *Lymnea*, and *Paludina*. (See figures.) But to these are occasionally added *Physa*, *Succinea*, *Ancylus*, *Valvata*, *Melanopsis*, *Melania*, and *Neritina*. (See figures.)

Fig. 31.

Planorbis euomphalus; fossil. Isle of Wight.

Fig. 32.



Lymnea longiscata; fossil. Hants.

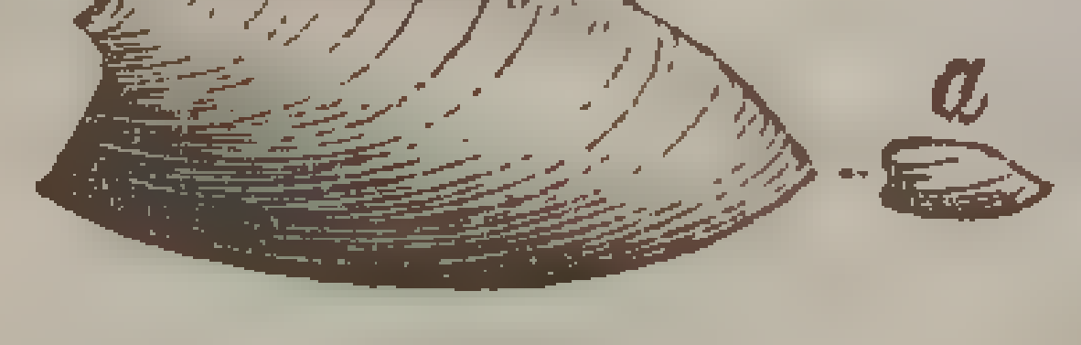
Fig. 33.

Paludina lenta; fossil. Hants.

Fig. 34.

Succinea amphibia; fossil. Loess, Rhine.

Fig. 35.



Ancylus elegans; fossil. Hants.

Fig. 36.

Valvata; fossil. Grays, Essex.

Fig. 37.

Physa hypnorum; recent.

In regard to one of these, the *Ancylus* (fig. 35.), Mr. Gray observes that it sometimes differs in no respect from the marine *Siphonaria*, except in the animal. The shell, however, of the *Ancylus* is usually thinner.*

Fig. 38.

Auricula; recent. Ava.

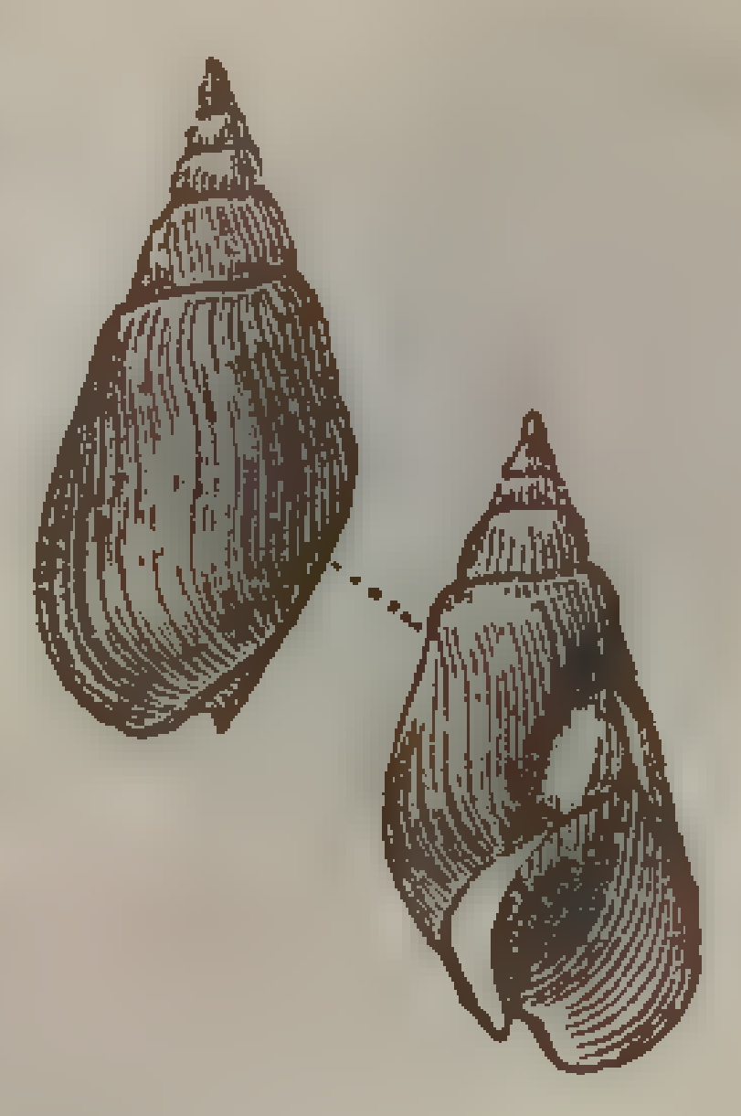
Fig. 39.

Melania inquinata. Paris basin.

Fig. 40.

Physa columnaris. Paris. basin.

Fig. 41.



Melanopsis buccinoidea; recent. Asia.

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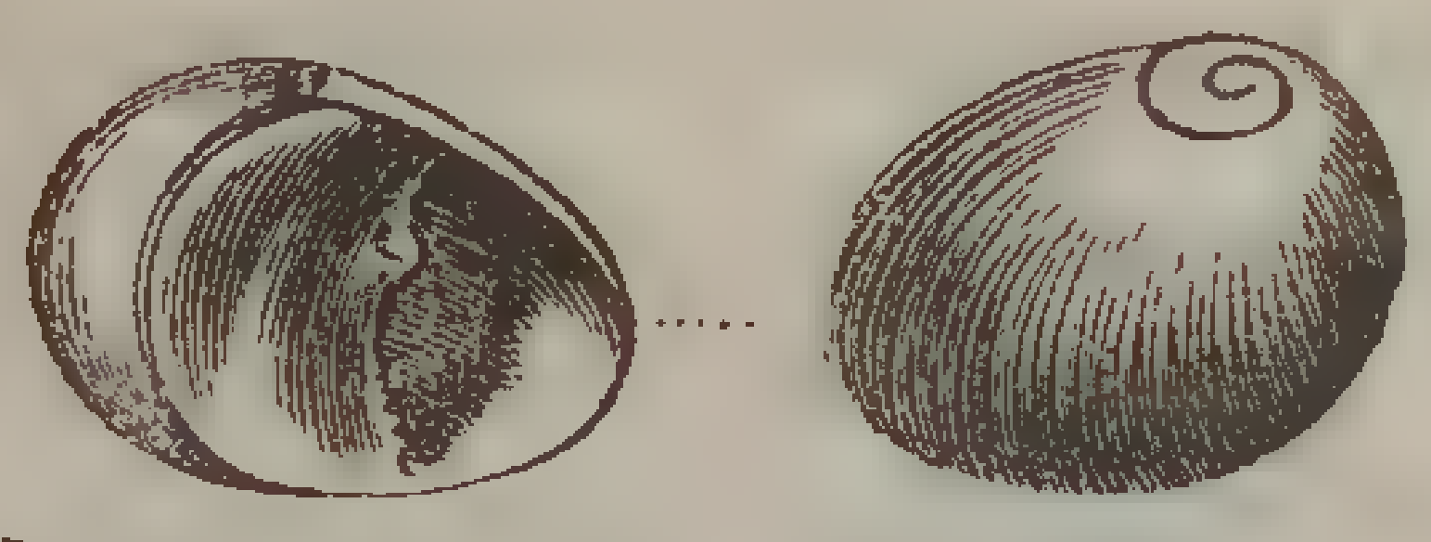
* Gray, Phil. Trans., 1835, p. 302.

Some naturalists include *Neritina* (fig. 42.) and the marine *Nerita* (fig. 43.) in the same genus, it being scarcely possible to distinguish the two by good generic characters. But, as a general rule, the fluviatile species are smaller, smoother, and more globular than the marine; and they have never, like the *Neritæ*, the inner margin of the outer lip toothed or crenulated. (See fig. 43.)

Fig. 42.



Neritina globulus. Paris basin.

Fig 43.

Nerita granulosa. Paris basin.

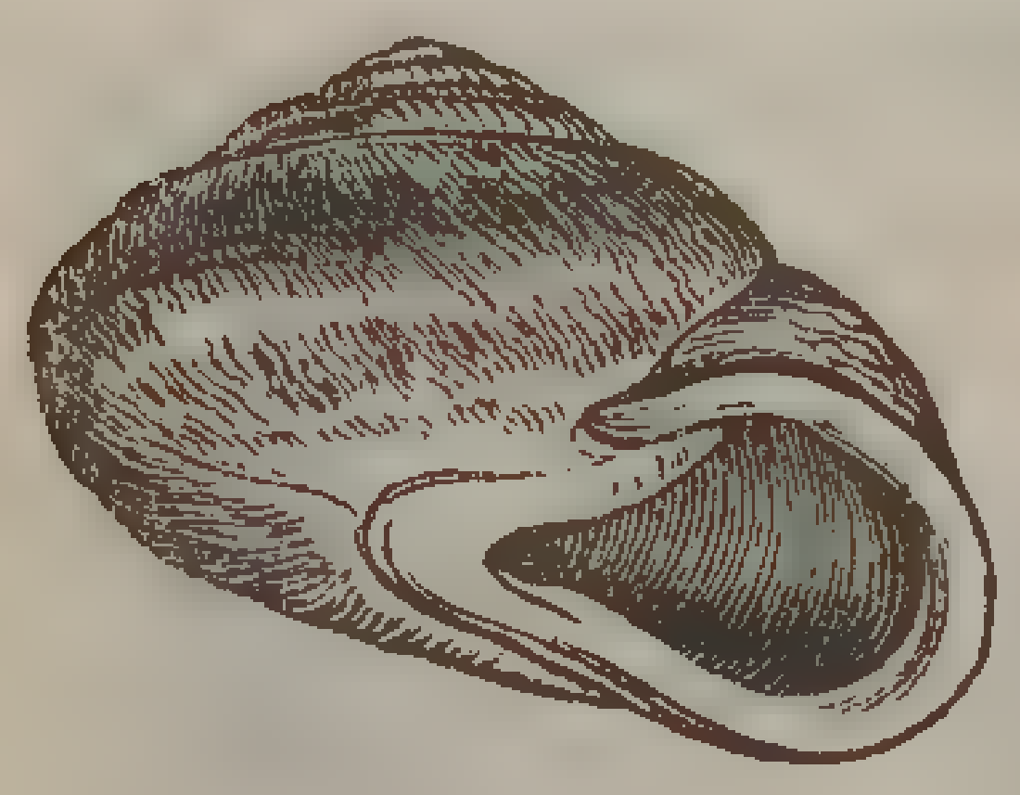
A few genera, among which *Cerithium* (fig. 44.) is the most abundant, are common both to rivers and the sea, having species peculiar to each. Other genera, like *Auricula* (fig. 38.), are amphibious, frequenting marshes, especially near the sea.

Fig. 44.

Cerithium cinctum. Paris basin.

The terrestrial shells are all univalves. The most abundant genera among these, both in a recent and fossil state, are *Helix* (fig. 45.), *Cyclostoma* (fig. 46.), *Pupa* (fig. 47.), *Clausilia* (fig. 48.), *Bulimus* (fig. 49.), and *Achatina;* which two last are nearly allied and pass into each other.

Fig. 45.

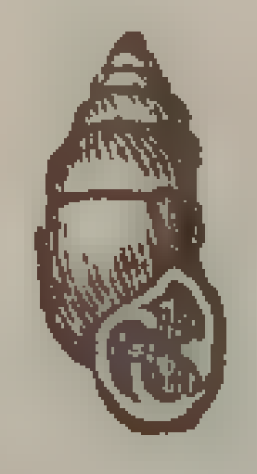


Helix Turonensis. Faluns, Touraine.

Fig. 46.

Cyclostoma elegans. Loess.

Fig. 47.

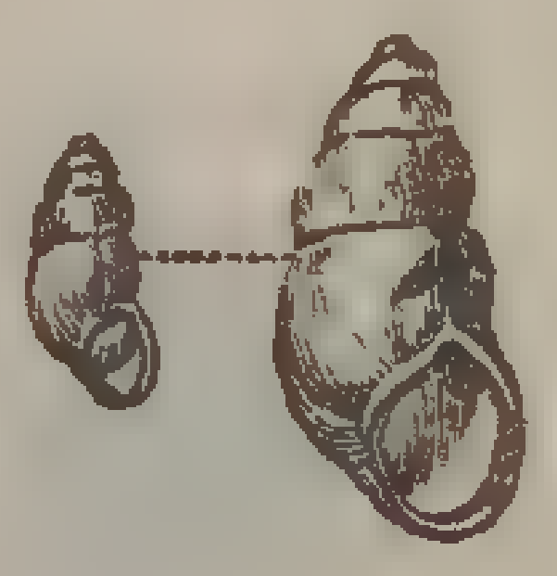


Pupa tridens. Loess.

Fig. 48.

Clausilia bidens. Loess.

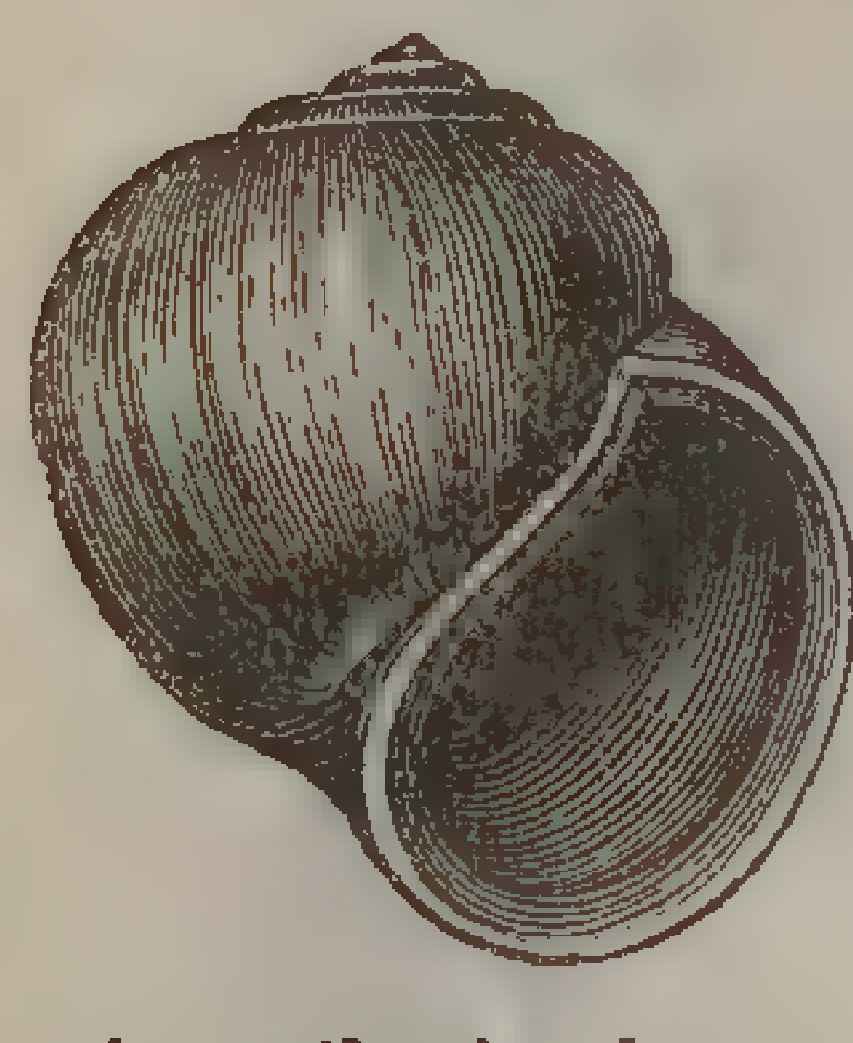
Fig. 49.



Bulimus lubricus. Loess, Rhine.

The *Ampullaria* (fig. 50.), is another genus of shells, inhabiting rivers and ponds in hot countries. Many fossil species have been referred to this genus, but they have been found chiefly in marine formations, and are suspected by some conchologists to belong to *Natica* and other marine genera.

Fig. 50.



Ampullaria glauca, from the Jumna.

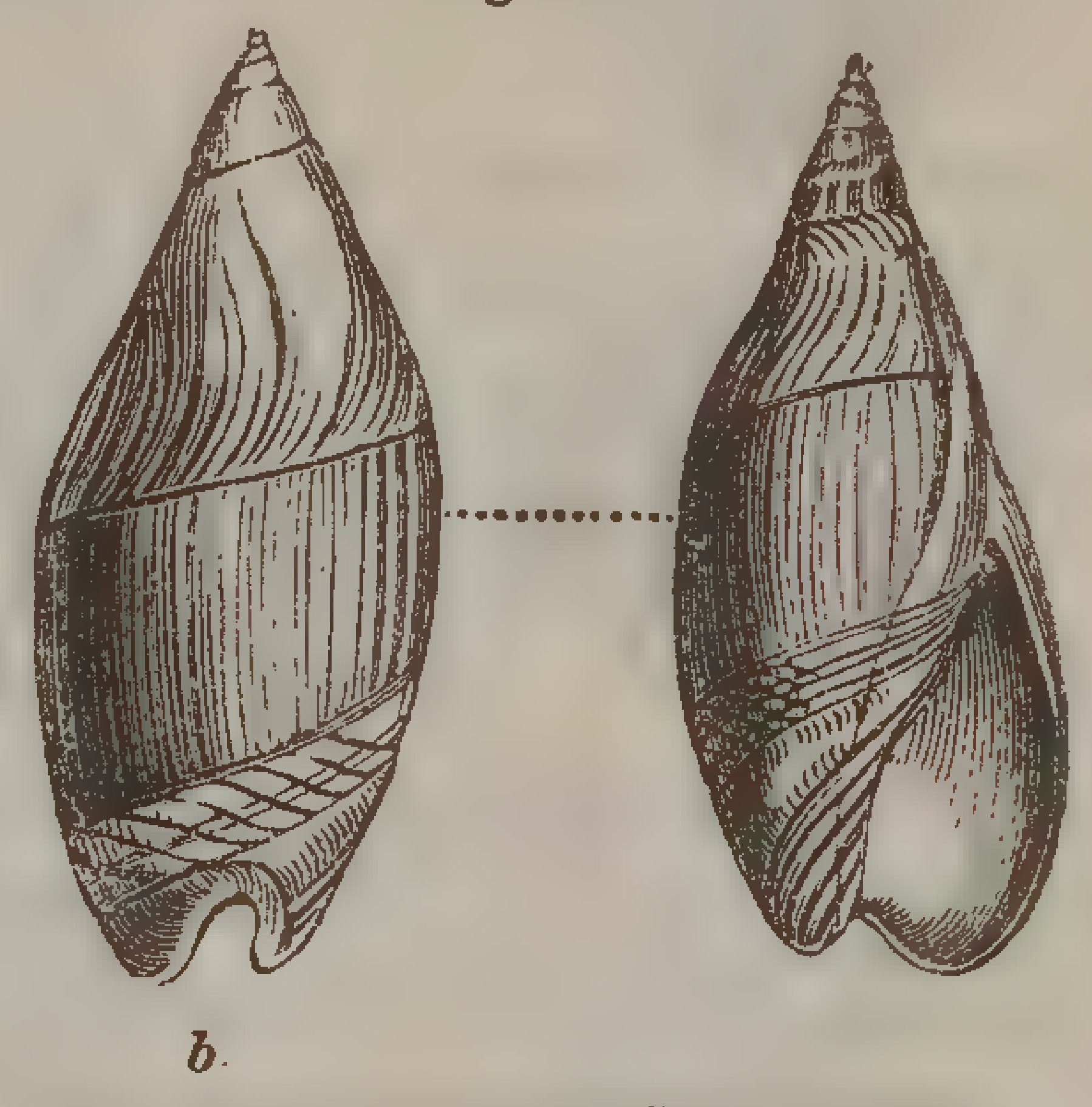
All univalve shells of land and freshwater species, with the exception of *Melanopsis* (fig. 41.), and *Achatina*, which has a slight indentation, have entire mouths; and this circumstance may often serve as a convenient rule for distinguishing freshwater from marine strata; since, if any univalves occur of which the mouths are not entire, we may presume that the formation is marine. The aperture is said to be entire in such shells as the *Ampullaria* and the land shells (figs. 45—49.), when its outline is not interrupted by an indentation or notch, such as that seen at *b* in *Ancillaria* (fig. 52.); or is not prolonged into a canal, as that seen at *a* in *Pleurotoma* (fig. 51.).

The mouths of a large proportion of the marine univalves have these notches or canals, and almost all such species are carnivorous;

Fig. 51.

Pleurotoma rotata. Subap. hills, Italy.

Fig. 52.



Ancillaria subulata. London clay.

whereas nearly all testacea having entire mouths, are plant-eaters; whether the species be marine, freshwater, or terrestrial.

There is, however, one genus which affords an occasional exception to one of the above rules. The *Cerithium* (fig. 44.), although provided with a short canal, comprises some species which inhabit salt, others brackish, and others fresh water, and they are said to be all plant-eaters.

Among the fossils very common in freshwater deposits are the shells of *Cypris*, a minute crustaceous animal, having a shell much resembling that of the bivalve mollusca.* Many minute living species of this genus swarm in lakes and stagnant pools in Great Britain; but their shells are not, if considered separately, conclusive as to the freshwater origin of a deposit, because the majority of species in another kindred genus of the same order, the *Cytherina* of Lamarck (see above, fig. 21. p. 26.), inhabit salt water; and, although the animal differs slightly, the shell is scarcely distinguishable from that of the *Cypris*.

The seed-vessels and stems of *Chara*, a genus of aquatic plants, are very frequent in freshwater strata. These seed-vessels were called, before their true nature was known, gyrogonites, and were supposed to be foraminiferous shells. (See fig. 53. *a*.)

The *Charæ* inhabit the bottom of lakes and ponds, and flourish mostly where the water is charged with carbonate of lime. Their seed-vessels are covered with a very tough integument, capable of resisting decomposition; to which circumstance we may attribute their abundance in a fossil state. The annexed figure (fig. 54.) represents a branch of one of many new species found by Professor Amici in the lakes of Northern Italy. The seed-vessel in this plant is more globular than in the British *Charæ*, and therefore more nearly resembles in form the extinct fossil species found in England,

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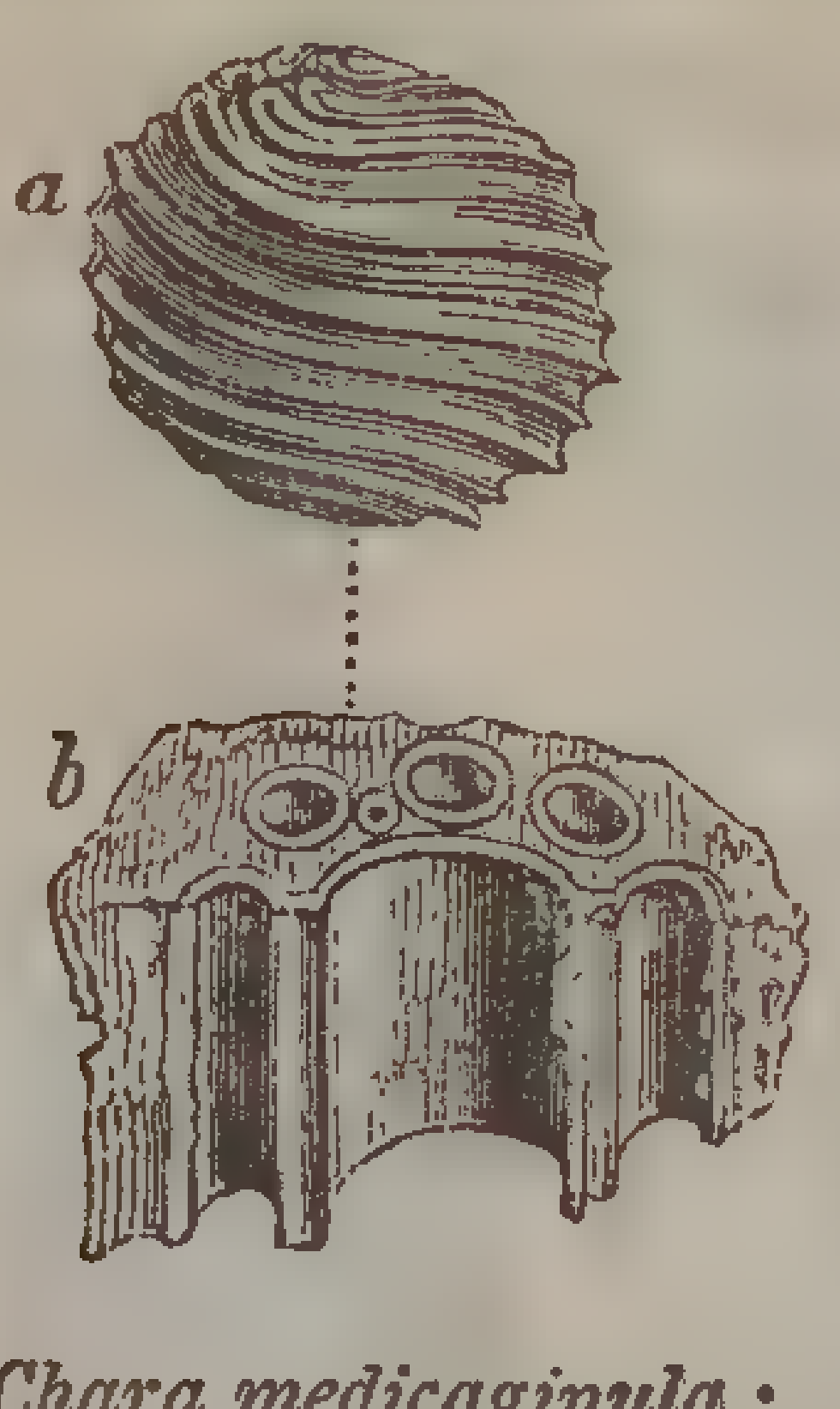
* For figures of fossil species of Purbeck, see below, ch. xx

France, and other countries. The stems, as well as the seed-vessels, of these plants occur both in modern shell marl and in ancient freshwater formations. They are generally composed of a large tube surrounded by smaller tubes; the whole stem being divided at certain intervals by transverse partitions or joints. (See *b*, fig. 53.)

Fig. 53.



Chara medicaginula; fossil. Upper Eocene, Isle of Wight.

a. Seed-vessel, magnified 20 diameters.
b. Stem, magnified.

Fig. 54.

Chara elastica; recent. Italy.

a. Sessile seed vessel between the divisions of the leaves of the female plant.
b. Magnified transverse section of a branch, with five seed-vessels, seen from below upwards.

It is not uncommon to meet with layers of vegetable matter, impressions of leaves, and branches of trees, in strata containing freshwater shells; and we also find occasionally the teeth and bones of land quadrupeds, of species now unknown. The manner in which such remains are occasionally carried by rivers into lakes, especially during floods, has been fully treated of in the "Principles of Geology."*

The remains of fish are occasionally useful in determining the freshwater origin of strata. Certain genera, such as carp, perch, pike, and loach (*Cyprinus*, *Perca*, *Esox*, and *Cobitis*), as also *Lebias*, being peculiar to freshwater. Other genera contain some freshwater and some marine species, as *Cottus*, *Mugil*, and *Anguilla*, or eel. The rest are either common to rivers and the sea, as the salmon; or are exclusively characteristic of salt water. The above observations respecting fossil fishes are applicable only to the more modern or tertiary deposits; for in the more ancient rocks the forms depart so widely from those of existing fishes, that it is very difficult, at least in the present state of science, to derive any positive information from icthyolites respecting the element in which strata were deposited.

The alternation of marine and freshwater formations, both on a small and large scale, are facts well ascertained in geology. When it occurs on a small scale, it may have arisen from the alternate occupation of certain spaces by river water and the sea; for in the flood season the river forces back the ocean and freshens it over a large area, depositing at the same time its sediment; after which the salt water again returns, and, on resuming its former place, brings with it sand, mud, and marine shells.

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* See Index of Principles, "Fossilization."

There are also lagoons at the mouths of many rivers, as the Nile and Mississippi, which are divided off by bars of sand from the sea, and which are filled with salt and fresh water by turns. They often communicate exclusively with the river for months, years, or even centuries; and then a breach being made in the bar of sand, they are for long periods filled with salt water.

The Lym-Fiord in Jutland offers an excellent illustration of analogous changes; for, in the course of the last thousand years, the western extremity of this long frith, which is 120 miles in length, including its windings, has been four times fresh and four times salt, a bar of sand between it and the ocean having been as often formed and removed. The last irruption of salt water happened in 1824, when the North Sea entered, killing all the freshwater shells, fish, and plants; and from that time to the present, the sea-weed *Fucus vesiculosus*, together with oysters and other marine mollusca, have succeeded the *Cyclas*, *Lymnea*, *Paludina*, and *Charæ*.*

But changes like these in the Lym-Fiord, and those before mentioned as occurring at the mouths of great rivers, will only account for some cases of marine deposits of partial extent resting on freshwater strata. When we find, as in the south-east of England, a great series of freshwater beds, 1000 feet in thickness, resting upon marine formations and again covered by other rocks, such as the cretaceous, more than 1000 feet thick, and of deep-sea origin, we shall find it necessary to seek for a different explanation of the phenomena.†

CHAPTER IV.

CONSOLIDATION OF STRATA AND PETRIFACTION OF FOSSILS.

Chemical and mechanical deposits — Cementing together of particles — Hardening by exposure to air — Concretionary nodules — Consolidating effects of pressure — Mineralization of organic remains — Impressions and casts how formed — Fossil wood — Göppert's experiments — Precipitation of stony matter most rapid where putrefaction is going on — Source of lime in solution — Silex derived from decomposition of felspar — Proofs of the lapidification of some fossils soon after burial, of others when much decayed.

HAVING spoken in the preceding chapters of the characters of sedimentary formations, both as dependent on the deposition of inorganic matter and the distribution of fossils, I may next treat of the consolidation of stratified rocks, and the petrifaction of imbedded organic remains.

Chemical and mechanical deposits. — A distinction has been made

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* See Principles, Index, "Lym-Fiord."

† See below, Chap. XVIII., on the Wealden.

by geologists between deposits of a chemical, and those of a mechanical, origin. By the latter name are designated beds of mud, sand, or pebbles produced by the action of running water, also accumulations of stones and scoriæ thrown out by a volcano, which have fallen into their present place by the force of gravitation. But the matter which forms a chemical deposit has not been mechanically suspended in water, but in a state of solution until separated by chemical action. In this manner carbonate of lime is often precipitated upon the bottom of lakes and seas in a solid form, as may be well seen in many parts of Italy, where mineral springs abound, and where the calcareous stone, called travertin, is deposited. In these springs the lime is usually held in solution by an excess of carbonic acid, or by heat if it be a hot spring, until the water, on issuing from the earth, cools or loses part of its acid. The calcareous matter then falls down in a solid state, encrusting shells, fragments of wood and leaves, and binding them together.*

In coral reefs, large masses of limestone are formed by the stony skeletons of zoophytes; and these. together with shells, become cemented together by carbonate of lime, part of which is probably furnished to the sea water by the decomposition of dead corals. Even shells of which the animals are still living, on these reefs, are very commonly found to be encrusted over with a hard coating of limestone.†

If sand and pebbles are carried by a river into the sea, and these are bound together immediately by carbonate of lime, the deposit may be described as of a mixed origin, partly chemical, and partly mechanical.

Now, the remarks already made in Chapter II. on the original horizontality of strata are strictly applicable to mechanical deposits, and only partially to those of a mixed nature. Such as are purely chemical may be formed on a very steep slope, or may even encrust the vertical walls of a fissure, and be of equal thickness throughout; but such deposits are of small extent, and for the most part confined to vein-stones.

Cementing of particles. — It is chiefly in the case of calcareous rocks that solidification takes place at the time of deposition. But there are many deposits in which a cementing process comes into operation long afterwards. We may sometimes observe, where the water of ferruginous or calcareous springs has flowed through a bed of sand or gravel, that iron or carbonate of lime has been deposited in the interstices between the grains or pebbles, so that in certain places the whole has been bound together into a stone, the same set of strata remaining in other parts loose and incoherent.

Proofs of a similar cementing action are seen in a rock at Kelloway in Wiltshire. A peculiar band of sandy strata belonging to the group called Oolite by geologists, may be traced through several

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* See Principles, Index, "Calcareous Springs," &c.

† Ibid. "Travertin," "Coral Reefs," &c.

counties, the sand being for the most part loose and unconsolidated, but becoming stony near Kelloway. In this district there are numerous fossil shells which have decomposed, having for the most part left only their casts. The calcareous matter hence derived has evidently served, at some former period, as a cement to the siliceous grains of sand, and thus a solid sandstone has been produced. If we take fragments of many other argillaceous grits, retaining the casts of shells, and plunge them into dilute muriatic or other acid, we see them immediately changed into common sand and mud; the cement of lime, derived from the shells, having been dissolved by the acid.

Traces of impressions and casts are often extremely faint. In some loose sands of recent date we meet with shells in so advanced a stage of decomposition as to crumble into powder when touched. It is clear that water percolating such strata may soon remove the calcareous matter of the shell; and unless circumstances cause the carbonate of lime to be again deposited, the grains of sand will not be cemented together; in which case no memorial of the fossil will remain. The absence of organic remains from many aqueous rocks may be thus explained; but we may presume that in many of them no fossils were ever imbedded, as there are extensive tracts on the bottoms of existing seas even of moderate depth on which no fragment of shell, coral, or other living creature can be detected by dredging. On the other hand, there are depths where the zero of animal life has been approached; as, for example, in the Mediterranean, at the depth of about 230 fathoms, according to the researches of Prof. E. Forbes. In the Ægean Sea a deposit of yellowish mud of a very uniform character, and closely resembling chalk, is going on in regions below 230 fathoms, and this formation must be wholly devoid of organic remains.*

In what manner silex and carbonate of lime may become widely diffused in small quantities through the waters which permeate the earth's crust will be spoken of presently, when the petrifaction of fossil bodies is considered; but I may remark here that such waters are always passing in the case of thermal springs from hotter to colder parts of the interior of the earth; and, as often as the temperature of the solvent is lowered, mineral matter has a tendency to separate from it and solidify. Thus a stony cement is often supplied to sand, pebbles, or any fragmentary mixture. In some conglomerates, like the pudding-stone of Hertfordshire (a Lower Eocene deposit), pebbles of flint and grains of sand are united by a siliceous cement so firmly, that if a block be fractured the rent passes as readily through the pebbles as through the cement.

It is probable that many strata became solid at the time when they emerged from the waters in which they were deposited, and when they first formed a part of the dry land. A well-known fact seems to confirm this idea: by far the greater number of the stones used for building and road-making are much softer when first taken from

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* Report Brit. Ass. 1843, p. 178.

the quarry than after they have been long exposed to the air; and these, when once dried, may afterwards be immersed for any length of time in water without becoming soft again. Hence it is found desirable to shape the stones which are to be used in architecture while they are yet soft and wet, and while they contain their "quarry-water," as it is called; also to break up stone intended for roads when soft, and then leave it to dry in the air for months that it may harden. Such induration may perhaps be accounted for by supposing the water, which penetrates the minutest pores of rocks, to deposit, on evaporation, carbonate of lime, iron, silex, and other minerals previously held in solution, and thereby to fill up the pores partially. These particles, on crystallizing, would not only be themselves deprived of freedom of motion, but would also bind together other portions of the rock which before were loosely aggregated. On the same principle wet sand and mud become as hard as stone when frozen; because one ingredient of the mass, namely, the water, has crystallized, so as to hold firmly together all the separate particles of which the loose mud and sand were composed.

Dr. MacCulloch mentions a sandstone in Skye, which may be moulded like dough when first found; and some simple minerals, which are rigid and as hard as glass in our cabinets, are often flexible and soft in their native beds: this is the case with asbestos, sahlite, tremolite, and chalcedony, and it is reported also to happen in the case of the beryl.*

The marl recently deposited at the bottom of Lake Superior, in North America, is soft, and often filled with freshwater shells; but if a piece be taken up and dried, it becomes so hard that it can only be broken by a smart blow of the hammer. If the lake therefore was drained, such a deposit would be found to consist of strata of marlstone, like that observed in many ancient European formations, and like them containing freshwater shells.

It is probable that some of the heterogeneous materials which rivers transport to the sea may at once set under water, like the artificial mixture called pozzolana, which consists of fine volcanic sand charged with about 20 per cent. of oxide of iron, and the addition of a small quantity of lime. This substance hardens, and becomes a solid stone in water, and was used by the Romans in constructing the foundations of buildings in the sea.

Consolidation in these cases is brought about by the action of chemical affinity on finely comminuted matter previously suspended in water. After deposition similar particles seem to exert a mutual attraction on each other, and congregate together in particular spots, forming lumps, nodules, and concretions. Thus in many argillaceous deposits there are calcareous balls, or spherical concretions, ranged in layers parallel to the general stratification; an arrangement which took place after the shale or marl had been thrown down in successive laminæ; for these laminæ are often traced in the concretions,

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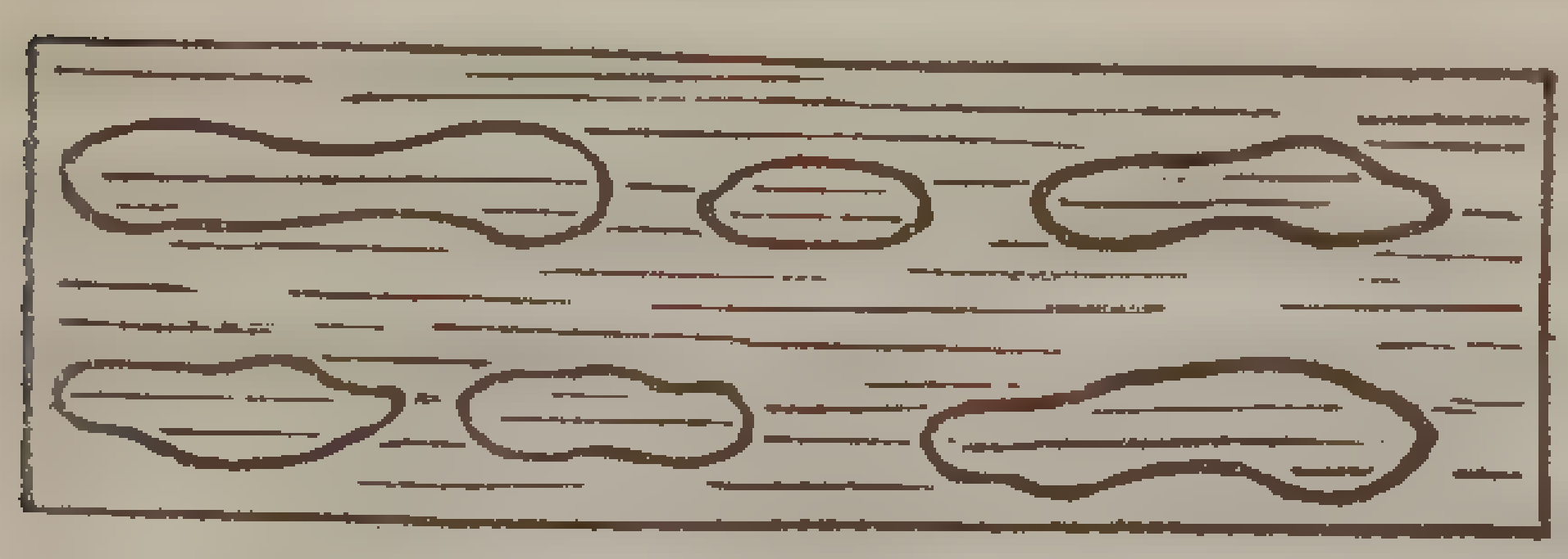
* Dr. MacCulloch, Syst. of Geol. vol. i. p. 123.

Fig. 55.

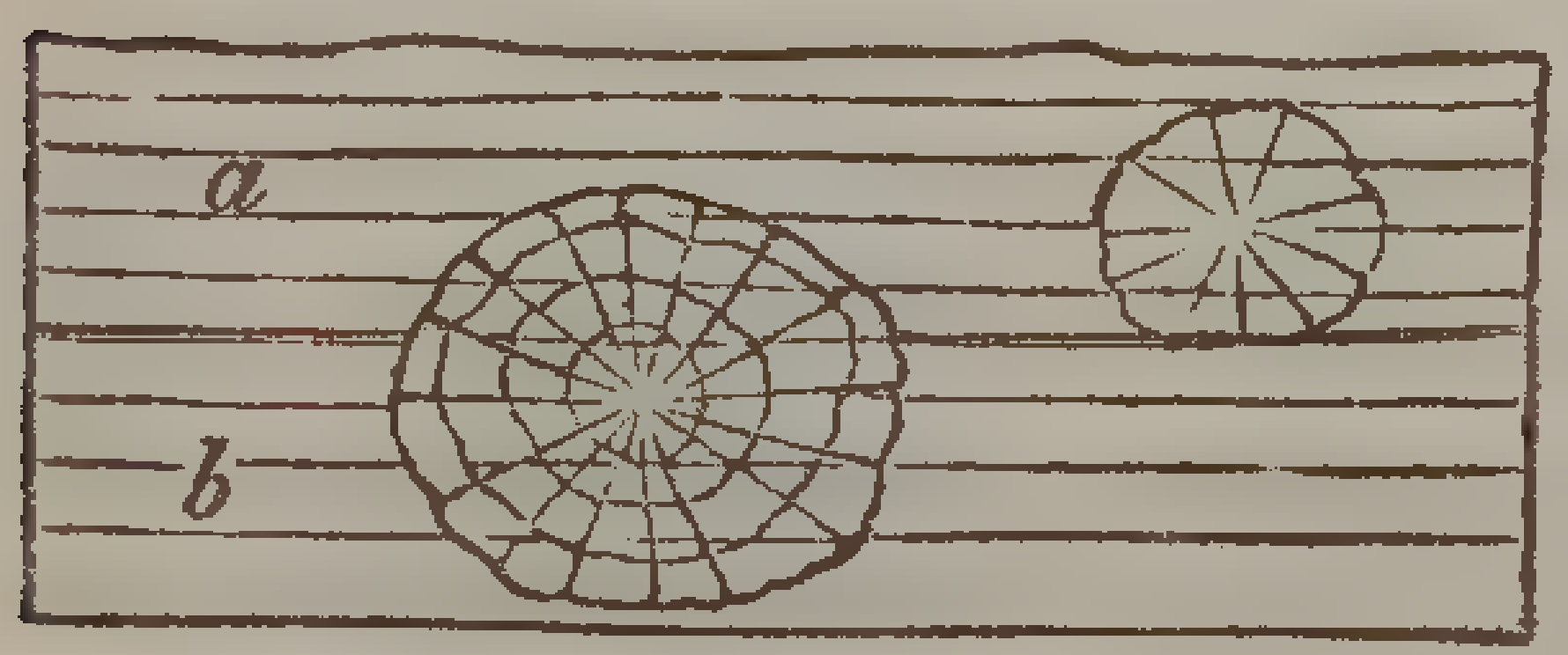


Calcareous nodules in Lias.

remaining parallel to those of the surrounding unconsolidated rock. (See fig. 55.) Such nodules of limestone have often a shell or other foreign body in the centre.*

Among the most remarkable examples of concretionary structure are those described by Professor Sedgwick as abounding in the magnesian limestone of the north of England. The spherical balls are of various sizes, from that of a pea to a diameter of several feet, and they have both a concentric and radiated structure, while at the same time the laminæ of original deposition pass uninterruptedly through them. In some cliffs this limestone resembles a great irregular pile of cannon balls. Some of the globular masses have their centre in one stratum, while a portion of their exterior passes through to the stratum above or below. Thus the larger spheroid in the annexed section (fig. 56.) passes from the stratum *b* upwards into *a*. In this instance we must suppose the deposition of a series of minor layers, first forming the stratum *b*, and afterwards the incumbent stratum *a*; then a movement of the particles took place, and the carbonates of lime and magnesia separated from the more impure and mixed matter forming the still unconsolidated parts of the stratum. Crystallization, beginning at the centre, must have gone on forming concentric coats around the original nucleus without interfering with the laminated structure of the rock.

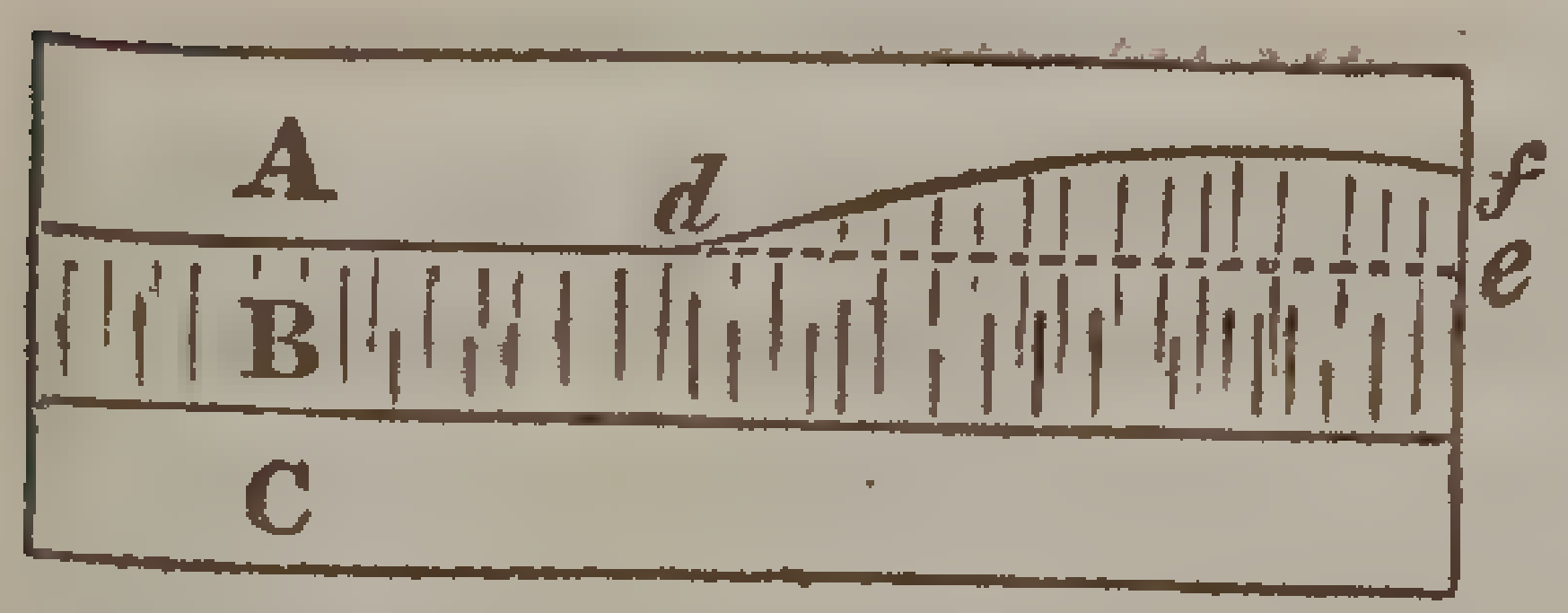
Fig. 56.



Spheroidal concretions in magnesian limestone.

When the particles of rocks have been thus re-arranged by chemical forces, it is sometimes difficult or impossible to ascertain whether certain lines of division are due to original deposition or to the subsequent aggregation of similar particles. Thus suppose three strata of grit, A, B, C, are charged unequally with calcareous matter, and that B is the most calcareous. If consolidation takes place in B, the concretionary action may spread upwards into a part of A, where the carbonate of lime is more abundant than in the rest; so that a mass, *d*, *e*, *f*, forming a portion of the superior stratum, becomes united with B into one solid mass of stone. The original line of division *d*, *e*, being thus effaced, the line *d*, *f*, would generally be considered as the surface of the bed B, though not strictly a true plane of stratification.

Fig. 57.



Pressure and heat.—When sand and mud sink to the bottom of a deep sea, the particles are not pressed down by the enormous weight of the incumbent ocean; for the water, which becomes mingled with the sand and mud, resists pressure with a force equal to that of the column of fluid above. The same happens in regard to organic re-

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* De la Beche, Geol. Researches, p. 95., and Geol. Observer (1851), p. 686.

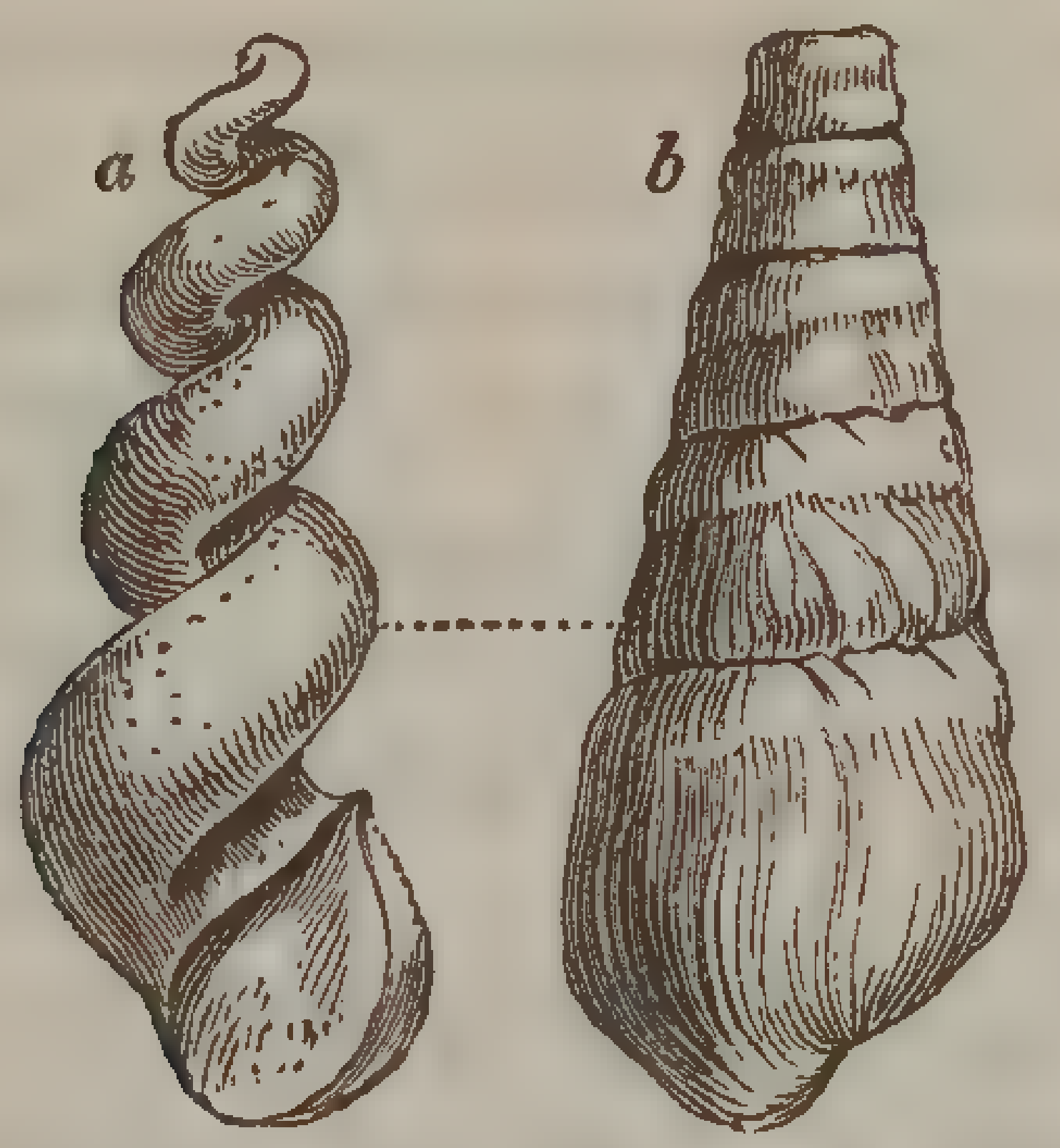
mains which are filled with water under great pressure a they sink otherwise they would be immediately crushed to pieces and flattened. Nevertheless, if the materials of a stratum remain in a yielding state, and do not set or solidify, they will be gradually squeezed down by the weight of other materials successively heaped upon them, just as soft clay or loose sand on which a house is built may give way. By such downward pressure particles of clay, sand, and marl, may become packed into a smaller space, and be made to cohere together permanently.

Analogous effects of condensation may arise when the solid parts of the earth's crust are forced in various directions by those mechanical movements afterwards to be described, by which strata have been bent, broken, and raised above the level of the sea. Rocks of more yielding materials must often have been forced against others previously consolidated, and, thus compressed, may have acquired a new structure. A recent discovery may help us to comprehend how fine sediment derived from the detritus of rocks may be solidified by mere pressure. The graphite or "black lead" of commerce having become very scarce, Mr. Brockedon contrived a method by which the dust of the purer portions of the mineral found in Borrowdale might be recomposed into a mass as dense and compact as native graphite. The powder of graphite is first carefully prepared and freed from air, and placed under a powerful press on a strong steel die, with air-tight fittings. It is then struck several blows, each of a power of 1000 tons; after which operation the powder is so perfectly solidified that it can be cut for pencils, and exhibits when broken the same texture as native graphite.

But the action of heat at various depths in the earth is probably the most powerful of all causes in hardening sedimentary strata. To this subject I shall refer again when treating of the metamorphic rocks, and of the slaty and jointed structure.

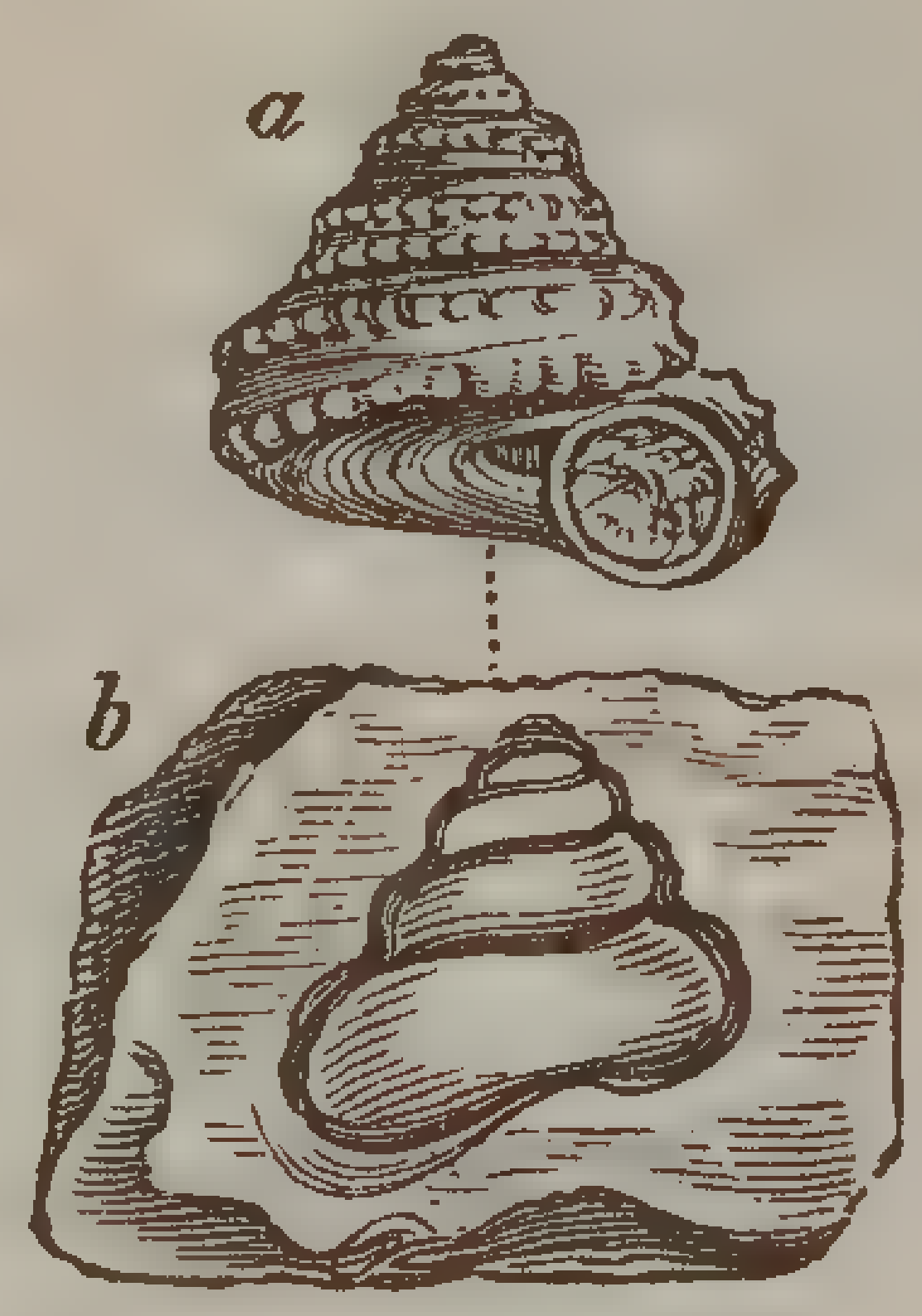
Mineralization of organic remains. — The changes which fossil organic bodies have undergone since they were first imbedded in rocks, throw much light on the consolidation of strata. Fossil shells in some modern deposits have been scarcely altered in the course of centuries, having simply lost a part of their animal matter. But in other cases the shell has disappeared, and left an impression only of its exterior, or a cast of its interior form, or thirdly, a cast of the shell itself, the original matter of which has been removed. These different forms of fossilization may easily be understood if we examine the mud recently thrown out from a pond or canal in which there are shells. If the mud be argillaceous, it acquires consistency on drying, and on breaking open a portion of it we find that each shell has left impressions of its external form. If we then remove the shell itself, we find within a solid nucleus of clay, having the form of the interior of the shell. This form is often very different from that of the outer shell. Thus a cast such as *a*, fig. 58., commonly called a fossil screw, would never be suspected by an inexperienced conchologist to be the internal shape of the fossil univalve, *b*, fig. 58. Nor should we have imagined at first sight that the shell *a* and the cast *b*, fig. 59., were different parts of the same fossil. The reader will observe, in the last-mentioned figure (*b*, fig. 59.), that an empty space shaded dark, which the *shell itself* once occupied, now intervenes between the enveloping stone and the cast of the smooth interior of the whorls. In such cases the shell has been dissolved and the component particles removed by water percolating the rock. If the nucleus were taken out, a hollow mould would remain, on which the external form of the shell with its tubercles and striæ, as seen in *a*, fig. 59., would be seen embossed. Now if the space alluded to between the nucleus and the impression, instead of being left empty, has been filled up with calcareous spar, flint, pyrites, or other mineral, we then obtain from the mould an exact cast both of the external and internal form of the original shell. In this manner silicified casts of shells have been formed; and if the mud or sand of the nucleus happen to be incoherent, or soluble in acid, we can then procure in flint an empty shell, which in shape is the exact counterpart of the original. This cast may be compared to a bronze statue, representing merely the superficial form, and not the internal organization; but there is another description of petrifaction by no means uncommon, and of a much more wonderful kind, which may be compared to certain anatomical models in wax, where not only the outward forms and features, but the nerves, blood-vessels, and other internal organs are also shown. Thus we find corals, originally calcareous, in which not only the general shape, but also the minute and complicated internal organization are retained in flint.

Fig. 58.



Phasianella Heddingtonensis, and cast of the same. Coral Rag.

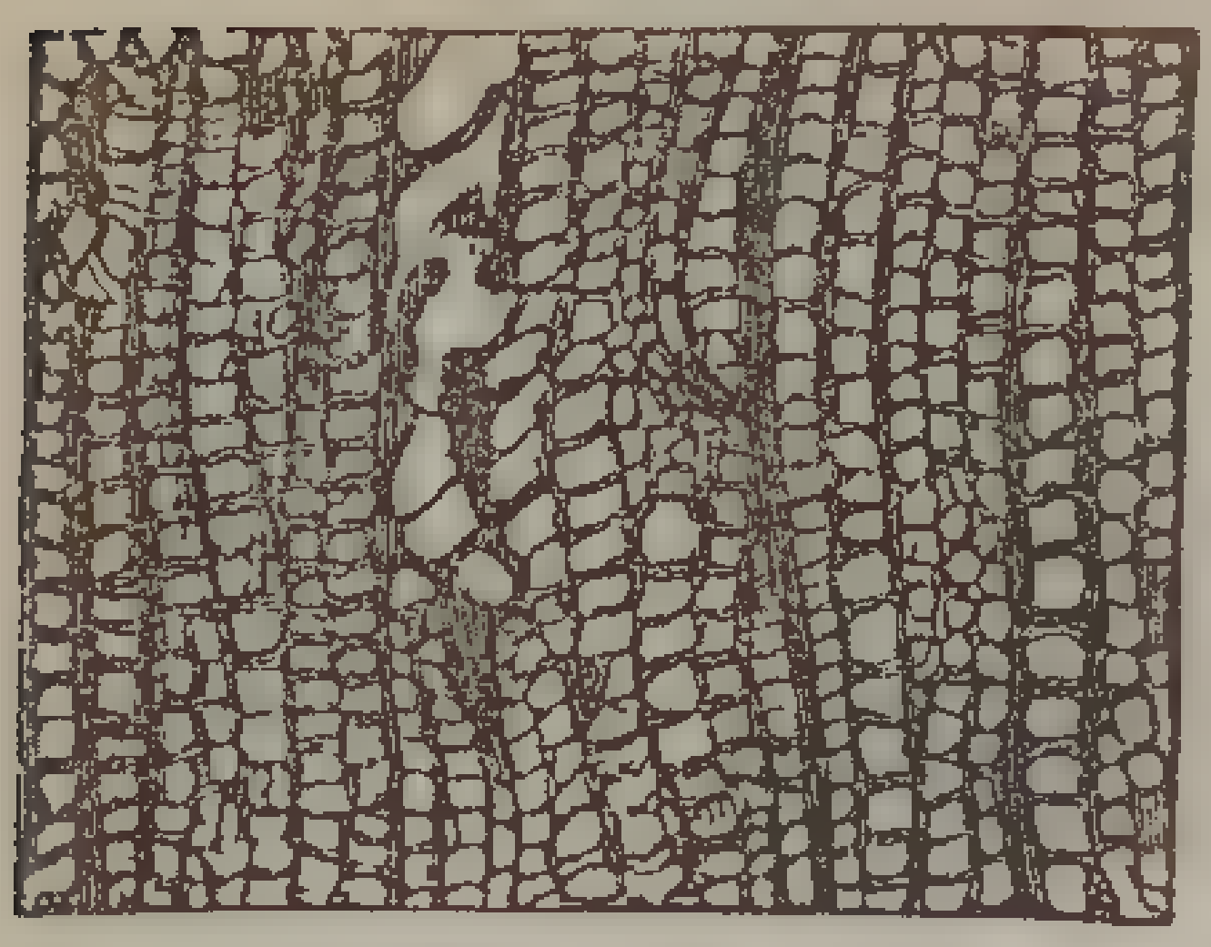
Fig. 59.



Trochus Anglicus, and cast. Lias.

Such a process of petrifaction is still more remarkably exhibited in fossil wood, in which we often perceive not only the rings of annual growth, but all the minute vessels and medullary rays. Many of the minute pores and fibres of plants, and even those spiral vessels which in the living vegetable can only be discovered by the microscope, are preserved. Among many instances, I may mention a fossil tree, 72 feet in length, found at Gosforth near Newcastle, in sandstone strata associated with coal. By cutting a transverse slice so thin as to transmit light, and magnifying it about fifty-five times, the texture seen in fig. 60. is exhibited. A texture equally minute and complicated has been observed in the wood of large trunks of fossil trees found in the Craigleith quarry near Edinburgh, where the stone was not in the slightest degree siliceous, but consisted chiefly of carbonate of lime, with oxide of iron, alumina, and carbon. The parallel rows of vessels here seen are the rings of annual growth, but in one part they are imperfectly preserved, the wood having probably decayed before the mineralizing matter had penetrated to that portion of the tree.

Fig. 60.



Texture of a tree from the coal strata, magnified. (Witham.) Transverse section.

In attempting to explain the process of petrifaction in such cases, we may first assume that strata are very generally permeated by water charged with minute portions of calcareous, siliceous, and other earths in solution. In what manner they become so impregnated will be afterwards considered. If an organic substance is exposed in the open air to the action of the sun and rain, it will in time putrefy, or be dissolved into its component elements, which consist chiefly of oxygen, hydrogen, and carbon. These will readily be absorbed by the atmosphere or be washed away by rain, so that all vestiges of the dead animal or plant disappear. But if the same substances be submerged in water, they decompose more gradually; and if buried in earth, still more slowly, as in the familiar example of wooden piles or other buried timber. Now, if as fast as each particle is set free by putrefaction in a fluid or gaseous state, a particle equally minute of carbonate of lime, flint, or other mineral, is at hand and ready to be precipitated, we may imagine this inorganic matter to take the place just before left unoccupied by the organic molecule. In this manner a cast of the interior of certain vessels may first be taken, and afterwards the more solid walls of the same may decay and suffer a like transmutation. Yet when the whole is lapidified, it may not form one homogeneous mass of stone or metal. Some of the original ligneous, osseous, or other organic elements may remain mingled in certain parts, or the lapidifying substance itself may be differently coloured at different times, or so crystallized as to reflect light differently, and thus the texture of the original body may be faithfully exhibited.

The student may perhaps ask whether, on chemical principles, we have any ground to expect that mineral matter will be thrown down precisely in those spots where organic decomposition is in progress? The following curious experiments may serve to illustrate this point. Professor Göppert of Breslau attempted recently to imitate the natural process of petrifaction. For this purpose he steeped a variety of animal and vegetable substances in waters, some holding siliceous, others calcareous, others metallic matter in solution. He found that in the period of a few weeks, or even days, the organic bodies thus immersed were mineralized to a certain extent. Thus, for example, thin vertical slices of deal, taken from the Scotch fir (*Pinus syl-*

vestris), were immersed in a moderately strong solution of sulphate of iron. When they had been thoroughly soaked in the liquid for several days they were dried and exposed to a red-heat until the vegetable matter was burnt up and nothing remained but an oxide of iron, which was found to have taken the form of the deal so exactly that casts even of the dotted vessels peculiar to this family of plants were distinctly visible under the microscope.

Another accidental experiment has been recorded by Mr. Pepys in the Geological Transactions.* An earthen pitcher containing several quarts of sulphate of iron had remained undisturbed and unnoticed for about a twelvemonth in the laboratory. At the end of this time when the liquor was examined an oily appearance was observed on the surface, and a yellowish powder, which proved to be sulphur, together with a quantity of small hairs. At the bottom were discovered the bones of several mice in a sediment consisting of small grains of pyrites, others of sulphur, others of crystallized green sulphate of iron, and a black muddy oxide of iron. It was evident that some mice had accidentally been drowned in the fluid, and by the mutual action of the animal matter and the sulphate of iron on each other, the metallic sulphate had been deprived of its oxygen; hence the pyrites and the other compounds were thrown down. Although the mice were not mineralized, or turned into pyrites, the phenomenon shows how mineral waters, charged with sulphate of iron, may be deoxydated on coming in contact with animal matter undergoing putrefaction, so that atom after atom of pyrites may be precipitated, and ready, under favourable circumstances, to replace the oxygen, hydrogen, and carbon into which the original body would be resolved.

The late Dr. Turner observes, that when mineral matter is in a "nascent state," that is to say, just liberated from a previous state of chemical combination, it is most ready to unite with other matter, and form a new chemical compound. Probably the particles or atoms just set free are of extreme minuteness, and therefore move more freely, and are more ready to obey any impulse of chemical affinity. Whatever be the cause, it clearly follows, as before stated, that where organic matter newly imbedded in sediment is decomposing, there will chemical changes take place most actively.

An analysis was lately made of the water which was flowing off from the rich mud deposited by the Hooghly river in the Delta of the Ganges after the annual inundation. This water was found to be highly charged with carbonic acid gas holding lime in solution.† Now if newly-deposited mud is thus proved to be permeated by mineral matter in a state of solution, it is not difficult to perceive that decomposing organic bodies, naturally imbedded in sediment, may as readily become petrified as the substances artificially immersed by Professor Göppert in various fluid mixtures.

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* Vol. i. p. 399. first series.

† Piddington, Asiat. Research. vol. xviii. p. 226.

It is well known that the water of springs, or that which is continually percolating the earth's crust, is rarely free from a slight admixture either of iron, carbonate of lime, sulphur, silica, potash, or some other earthy, alkaline, or metallic ingredient. Hot springs in particular are copiously charged with one or more of these elements; and it is only in their waters that silex is found in abundance. In certain cases, therefore, especially in volcanic regions, we may imagine the flint of silicified wood and corals to have been supplied by the waters of thermal springs. In other instances, as in tripoli, it may have been derived in great part, if not wholly, from the decomposition of diatomaceæ, sponges, and other bodies. But even if this be granted, we have still to inquire whence a lake or the ocean can be constantly replenished with the calcareous and siliceous matter so abundantly withdrawn from it by the secretions of living beings.

In regard to carbonate of lime there is no difficulty, because not only are calcareous springs very numerous, but even rain-water, when it falls on ground where vegetable matter is decomposing, may become so charged with carbonic acid as to acquire a power of dissolving a minute portion of the calcareous rocks over which it flows. Hence marine corals and mollusca may be provided by rivers with the materials of their shells and solid supports. But pure silex, even when reduced to the finest powder and boiled, is insoluble in water, except at very high temperatures. Nevertheless, Dr. Turner has well explained, in an essay on the chemistry of geology*, how the decomposition of felspar may be a source of silex in solution. He has remarked that the siliceous earth, which constitutes more than half the bulk of felspar, is intimately combined with alumine, potash, and some other elements. The alkaline matter of the felspar has a chemical affinity for water, as also for the carbonic acid which is more or less contained in the waters of most springs. The water therefore carries away alkaline matter, and leaves behind a clay consisting of alumine and silica. But this residue of the decomposed mineral, which in its purest state is called porcelain clay, is found to contain a part only of the silica which existed in the original felspar. The other part, therefore, must have been dissolved and removed: and this can be accounted for in two ways; first, because silica when combined with an alkali is soluble in water; secondly, because silica, in what is technically called its nascent state, is also soluble in water. Hence an endless supply of silica is afforded to rivers and the waters of the sea. For the felspathic rocks are universally distributed, constituting, as they do, so large a proportion of the volcanic, plutonic, and metamorphic formations. Even where they chance to be absent in mass, they rarely fail to occur in the superficial gravel or alluvial deposits of the basin of every large river.

The disintegration of mica also, another mineral which enters largely into the composition of granite and various sandstones, may

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* Jam. Ed. New Phil. Journ. No. 30. p. 246.

yield silica which may be dissolved in water, for nearly half of this mineral consists of silica, combined with alumine, potash, and about a tenth part of iron. The oxidation of this iron in the air is the principal cause of the waste of mica.

We have still, however, much to learn before the conversion of fossil bodies into stone is fully understood. Some phenomena seem to imply that the mineralization must proceed with considerable rapidity, for stems of a soft and succulent character, and of a most perishable nature, are preserved in flint; and there are instances of the complete silicification of the young leaves of a palm-tree when just about to shoot forth, and in that state which in the West Indies is called the cabbage of the palm.* It may, however, be questioned whether in such cases there may not have been some antiseptic quality in the water which retarded putrefaction, so that the soft parts of the buried substance may have remained for a long time without disintegration, like the flesh of bodies imbedded in peat.

Mr. Stokes has pointed out examples of petrifactions in which the more perishable, and others where the more durable, portions of wood are preserved. These variations, he suggests, must doubtless have depended on the time when the lapidifying mineral was introduced. Thus, in certain silicified stems of palm-trees, the cellular tissue, that most destructible part, is in good condition, while all signs of the hard woody fibre have disappeared, the spaces once occupied by it being hollow or filled with agate. Here, petrifaction must have commenced soon after the wood was exposed to the action of moisture, and the supply of mineral matter must then have failed, or the water must have become too much diluted before the woody fibre decayed. But when this fibre is alone discoverable, we must suppose that an interval of time elapsed before the commencement of lapidification, during which the cellular tissue was obliterated. When both structures, namely, the cellular and the woody fibre, are preserved, the process must have commenced at an early period, and continued without interruption till it was completed throughout.†

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* Stokes, Geol. Trans., vol. v. p. 212. second series.

† Ibid.

CHAPTER V.

ELEVATION OF STRATA ABOVE THE SEA—HORIZONTAL AND INCLINED STRATIFICATION.

Why the position of marine strata, above the level of the sea, should be referred to the rising up of the land, not to the going down of the sea—Upheaval of extensive masses of horizontal strata—Inclined and vertical stratification—Anticlinal and synclinal lines—Bent strata in east of Scotland—Theory of folding by lateral movement—Creeps—Dip and strike—Structure of the Jura—Various forms of outcrop—Rocks broken by flexure—Inverted position of disturbed strata—Unconformable stratification—Hutton and Playfair on the same—Fractures of strata—Polished surfaces—Faults—Appearance of repeated alternations produced by them—Origin of great faults.

Land has been raised, not the sea lowered.—It has been already stated that the aqueous rocks containing marine fossils extend over wide continental tracts, and are seen in mountain chains rising to great heights above the level of the sea (p. 4.). Hence it follows, that what is now dry land was once under water. But if we admit this conclusion, we must imagine, either that there has been a general lowering of the waters of the ocean, or that the solid rocks, once covered by water, have been raised up bodily out of the sea, and have thus become dry land. The earlier geologists, finding themselves reduced to this alternative, embraced the former opinion, assuming that the ocean was originally universal, and had gradually sunk down to its actual level, so that the present islands and continents were left dry. It seemed to them far easier to conceive that the water had gone down, than that solid land had risen upwards into its present position. It was, however, impossible to invent any satisfactory hypothesis to explain the disappearance of so enormous a body of water throughout the globe, it being necessary to infer that the ocean had once stood at whatever height marine shells might be detected. It moreover appeared clear, as the science of Geology advanced, that certain spaces on the globe had been alternately sea, then land, then estuary, then sea again, and, lastly, once more habitable land, having remained in each of these states for considerable periods. In order to account for such phenomena, without admitting any movement of the land itself, we are required to imagine several retreats and returns of the ocean; and even then our theory applies merely to cases where the marine strata composing the dry land are horizontal, leaving unexplained those more common instances where strata are inclined, curved, or placed on their edges, and evidently not in the position in which they were first deposited.

Geologists, therefore, were at last compelled to have recourse to the other alternative, namely, the doctrine that the solid land has been repeatedly moved upwards or downwards, so as permanently to change its position relatively to the sea. There are several distinct grounds for preferring this conclusion. First, it will account equally for the position of those elevated masses of marine origin in which the stratification remains horizontal, and for those in which the strata are disturbed, broken, inclined, or vertical. Secondly, it is consistent with human experience that land should rise gradually in some places and be depressed in others. Such changes have actually occurred in our own days, and are now in progress, having been accompanied in some cases by violent convulsions, while in others they have proceeded so insensibly, as to have been ascertainable only by the most careful scientific observations, made at considerable intervals of time. On the other hand, there is no evidence from human experience of a lowering of the sea's level in any region, and the ocean cannot sink in one place without its level being depressed all over the globe.

These preliminary remarks will prepare the reader to understand the great theoretical interest attached to all facts connected with the position of strata, whether horizontal or inclined, curved or vertical.

Now the first and most simple appearance is where strata of marine origin occur above the level of the sea in horizontal position. Such are the strata which we meet with in the south of Sicily, filled with shells for the most part of the same species as those now living in the Mediterranean. Some of these rocks rise to the height of more than 2000 feet above the sea. Other mountain masses might be mentioned, composed of horizontal strata of high antiquity, which contain fossil remains of animals wholly dissimilar from any now known to exist. In the south of Sweden, for example, near Lake Wener, the beds of one of the oldest of the fossiliferous deposits, namely that formerly called Transition, and now Silurian, by geologists, occur in as level a position as if they had recently formed part of the delta of a great river, and been left dry on the retiring of the annual floods. Aqueous rocks of about the same age extend for hundreds of miles over the lake-district of North America, and exhibit in like manner a stratification nearly undisturbed. The Table Mountain at the Cape of Good Hope is another example of highly elevated yet perfectly horizontal strata, no less than 3500 feet in thickness, and consisting of sandstone of very ancient date.

Instead of imagining that such fossiliferous rocks were always at their present level, and that the sea was once high enough to cover them, we suppose them to have constituted the ancient bed of the ocean, and that they were gradually uplifted to their present height. This idea, however startling it may at first appear, is quite in accordance, as before stated, with the analogy of changes now going on in certain regions of the globe. Thus, in parts of Sweden, and the shores and islands of the Gulf of Bothnia, proofs have been obtained that the land is experiencing, and has experienced for centuries, a slow upheaving movement. Playfair argued in favour of this opinion in 1802; and in 1807, Von Buch, after his travels in Scandinavia, announced his conviction that a rising of the land was in progress. Celsius and other Swedish writers had, a century before, declared their belief that a gradual change had, for ages, been taking place in the relative level of land and sea. They attributed the change to a fall of the waters both of the ocean and the Baltic. This theory, however, has now been refuted by abundant evidence; for the alteration of relative level has neither been universal nor everywhere uniform in quantity, but has amounted, in some regions, to several feet in a century, in others to a few inches; while in the southernmost part of Sweden, or the province of Scania, there has been actually a loss instead of a gain of land, buildings having gradually sunk below the level of the sea.*

It appears, from the observations of Mr. Darwin and others, that very extensive regions of the continent of South America have been undergoing slow and gradual upheaval, by which the level plains of Patagonia, covered with recent marine shells, and the Pampas of Buenos Ayres, have been raised above the level of the sea.† On the other hand, the gradual sinking of the west coast of Greenland, for the space of more than 600 miles from north to south, during the last four centuries, has been established by the observations of a Danish naturalist, Dr. Pingel. And while these proofs of continental elevation and subsidence, by slow and insensible movements, have been recently brought to light, the evidence has been daily strengthened of continued changes of level effected by violent convulsions in countries where earthquakes are frequent. There the rocks are rent from time to time, and heaved up or thrown down several feet at once, and disturbed in such a manner, that the original position of strata may, in the course of centuries, be modified to any amount.

It has also been shown by Mr. Darwin, that, in those seas where circular coral islands and barrier reefs abound, there is a slow and continued sinking of the submarine mountains on which the masses of coral are based; while there are other areas of the South Sea, where the land is on the rise, and where coral has been upheaved far above the sea-level.

It would require a volume to explain to the reader the various facts which establish the reality of these movements of land, whether of elevation or depression, whether accompanied by earthquakes or accomplished slowly and without local disturbance. Having treated fully of these subjects in the Principles of Geology‡, I shall assume, in the present work, that such changes are part of the actual course of nature; and when admitted, they will be found to afford a key to the interpretation of a variety of geological appearances, such as the elevation of horizontal, inclined, or disturbed marine strata, and the superposition of freshwater to marine deposits, afterwards to be described. It will also appear, in the sequel, how much light the

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* In the first three editions of my Principles of Geology, I expressed many doubts as to the validity of the alleged proofs of a gradual rise of land in Sweden; but after visiting that country, in 1834, I retracted these objections, and published a detailed statement of the observations which led me to alter my opinion in the Phil. Trans. 1835, Part I. See also the Principles, 4th and subsequent editions.

† See his Journal of a Naturalist in Voyage of the Beagle, and his work on Coral Reefs.

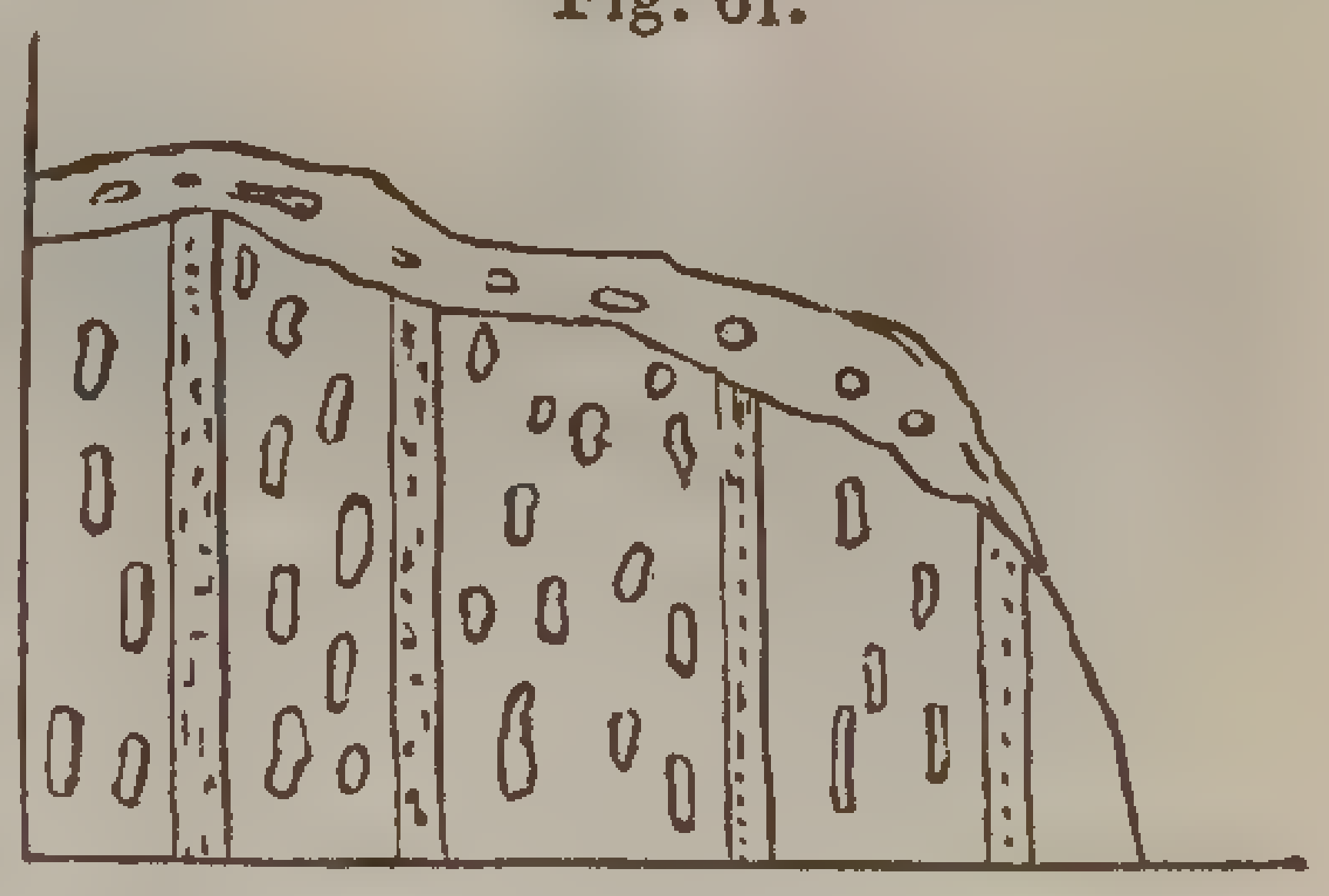
‡ See chaps. xxvii. to xxxii. inclusive, and chap. l.

doctrine of a continued subsidence of land may throw on the manner in which a series of strata, formed in shallow water, may have accumulated to a great thickness. The excavation of valleys also, and other effects of *denudation*, of which I shall presently treat, can alone be understood when we duly appreciate the proofs, now on record, of the prolonged rising and sinking of land, throughout wide areas.

To conclude this subject, I may remind the reader, that were we to embrace the doctrine which ascribes the elevated position of marine formations, and the depression of certain freshwater strata, to oscillations in the level of the waters instead of the land, we should be compelled to admit that the ocean has been sometimes every where much shallower than at present, and at others more than three miles deeper.

Inclined stratification. — The most unequivocal evidence of a change in the original position of strata is afforded by their standing up perpendicularly on their edges, which is by no means a rare phenomenon, especially in mountainous countries. Thus we find in Scotland, on the southern skirts of the Grampians, beds of puddingstone alternating with thin layers of fine sand, all placed vertically to the horizon. When Saussure first observed certain conglomerates in a similar position in the Swiss Alps, he remarked that the pebbles, being for the most part of an oval shape, had their longer axes parallel to the planes of stratification (see fig. 61.). From this he inferred, that such strata must, at first, have been horizontal, each oval pebble having originally settled at the bottom of the water, with its flatter side parallel to the horizon, for the same reason that an egg will not stand on either end if unsupported. Some few, indeed, of the rounded stones in a conglomerate occasionally afford an exception to the above rule, for the same reason that we see on a shingle beach some oval or flat-sided pebbles resting on their ends or edges; these having been forced along the bottom and against each other by a wave or current so as to settle in this position.

Fig. 61.

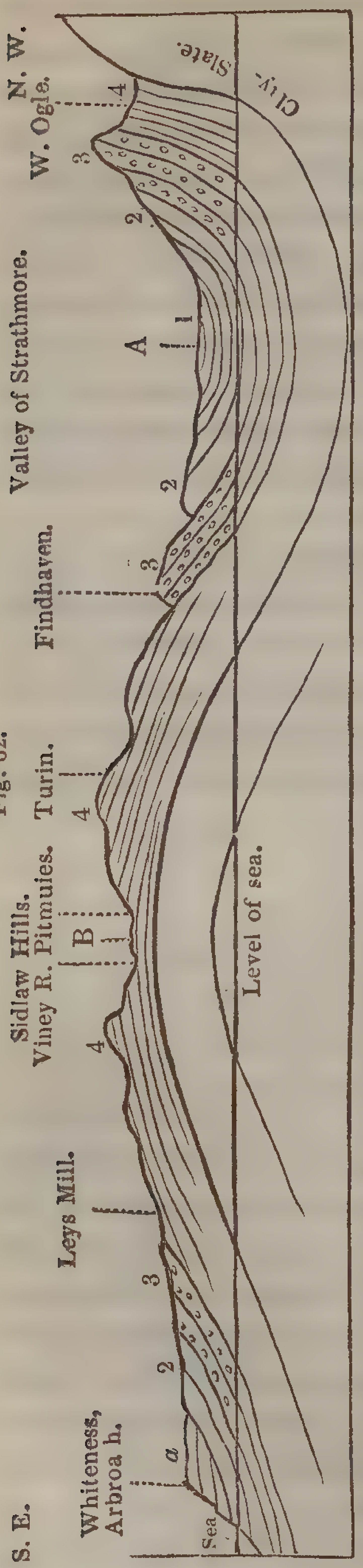


Vertical conglomerate and sandstone.

Vertical strata, when they can be traced continuously upwards or downwards for some depth, are almost invariably seen to be parts of great curves, which may have a diameter of a few yards, or of several miles. I shall first describe two curves of considerable regularity, which occur in Forfarshire, extending over a country twenty miles in breadth, from the foot of the Grampians to the sea near Arbroath.

The mass of strata here shown may be nearly 2000 feet in thickness, consisting of red and white sandstone, and various coloured shales, the beds being distinguishable into four principal groups, namely, No. 1. red marl or shale; No. 2. red sandstone, used for building; No. 3. conglomerate; and No. 4. grey paving-stone, and tile-stone, with green and reddish shale, containing peculiar organic remains. A glance at the section will show that each of the forma-

Fig. 62.



Section of Forfarshire, from N. W. to S. E., from foot of the Grampians to the sea at Arbroath (volcanic or trap rocks omitted). Length of section twenty miles.

tions 2, 3, 4, are repeated thrice at the surface, twice with a southerly, and once with a northerly inclination or *dip*, and the beds in No. 1., which are nearly horizontal, are still brought up twice by a slight curvature to the surface, once on each side of A. Beginning at the north-west extremity, the tile-stones and conglomerates No. 4. and No. 3. are vertical, and they generally form a ridge parallel to the southern skirts of the Grampians. The superior strata Nos. 2. and 1. become less and less inclined on descending to the valley of Strathmore, where the strata, having a concave bend, are said by geologists to lie in a "trough" or "basin." Through the centre of this valley runs an imaginary line A, called technically a "synclinal line," where the beds, which are tilted in opposite directions, may be supposed to meet. It is most important for the observer to mark such lines, for he will perceive by the diagram, that in travelling from the north to the centre of the basin, he is always passing from older to newer beds; whereas, after crossing the line A, and pursuing his course in the same southerly direction, he is continually leaving the newer, and advancing upon older strata. All the deposits which he had before examined begin then to recur in reversed order, until he arrives at the central axis of the Sidlaw hills, where the strata are seen to form an arch or *saddle*, having an *anticlinal* line B, in the centre. On passing this line, and continuing towards the S. E., the formations 4, 3, and 2, are again repeated, in the same relative order of superposition, but with a southerly dip. At Whiteness (see diagram) it will be seen that the inclined strata are covered by a newer deposit, *a*, in horizontal beds. These are composed of red conglomerate and sand, and are newer than any of the groups, 1, 2, 3, 4, before described, and rest *unconformably* upon strata of the sandstone group, No. 2.

An example of curved strata, in which the bends or convolutions of the rock are sharper and far more numerous within an equal space, has been well described by Sir James Hall.* It occurs near St.

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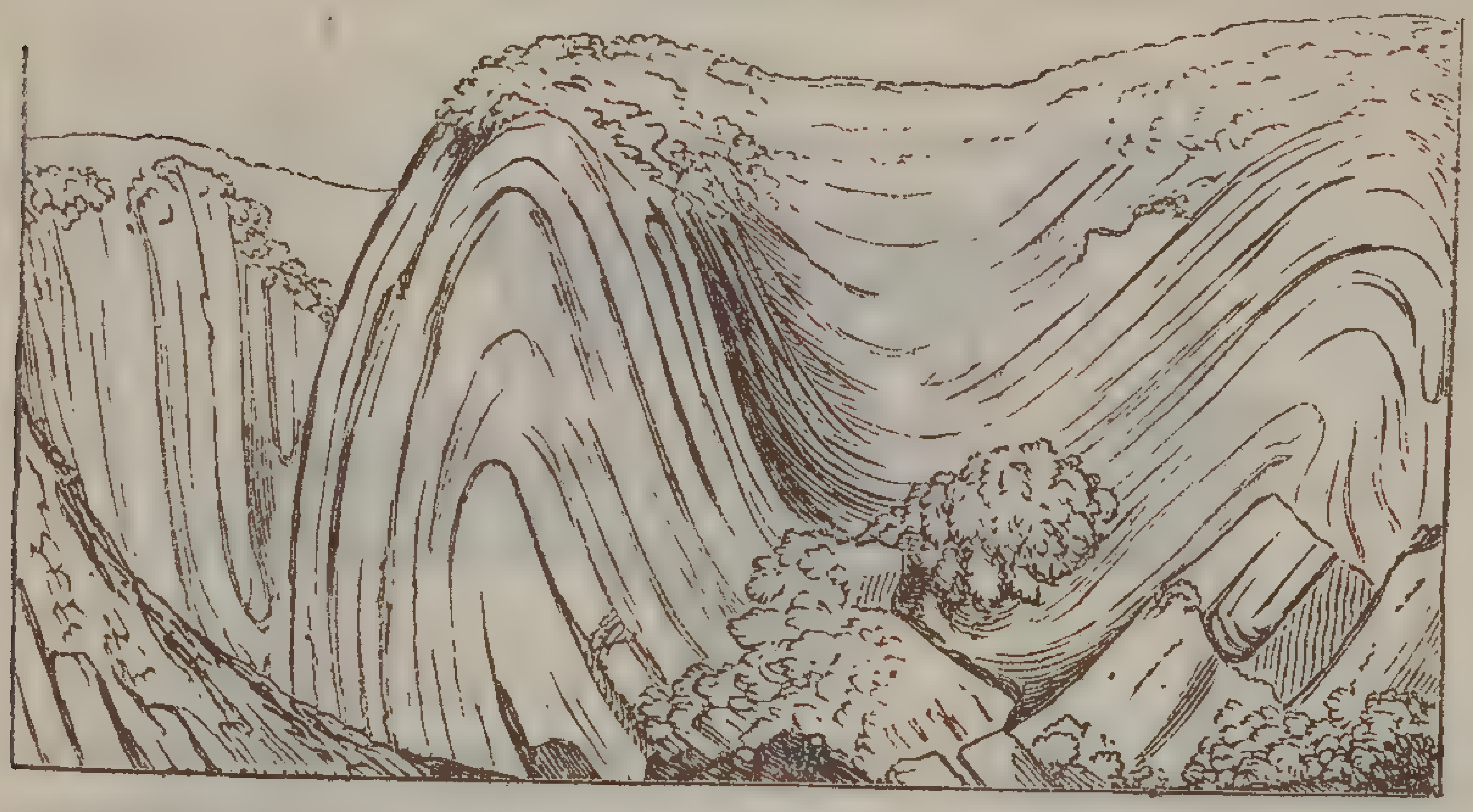
* Edin. Trans. vol. vii. pl. 3.

Abb's Head, on the east coast of Scotland, where the rocks consist principally of a bluish slate, having frequently a ripple-marked surface. The undulations of the beds reach from the top to the bottom of cliffs from 200 to 300 feet in height, and there are sixteen distinct bendings in the course of about six miles, the curvatures being alternately concave and convex upwards.

Fig. 63.



Curved strata of slate near St. Abb's Head, Berwickshire. (Sir J. Hall.)

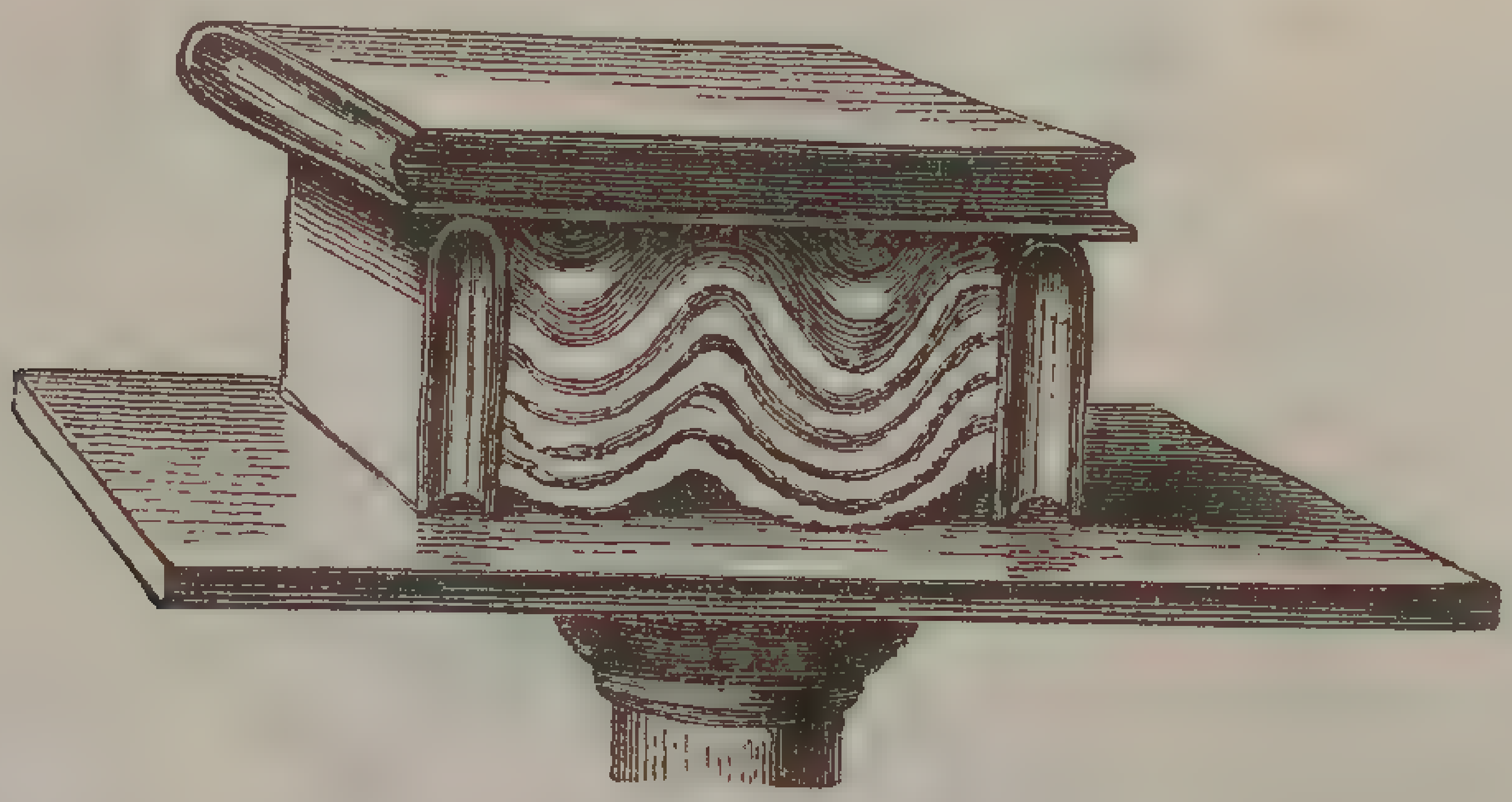
An experiment was made by Sir James Hall, with a view of illustrating the manner in which such strata, assuming them to have been originally horizontal, may have been forced into their present position. A set of layers of clay were placed under a weight, and their opposite ends pressed towards each other with such force as to cause them to approach more nearly together. On the removal of the weight, the layers of clay were found to be curved and folded, so as to bear a miniature resemblance to the strata in the cliffs. We must, however, bear in mind, that in the natural section or sea-cliff we only see the foldings imperfectly, one part being invisible beneath the sea, and the other, or upper portion, being supposed to have been carried away by *denudation*, or that action of water which will be explained in the next chapter. The dark lines in the accompanying plan (fig. 64.) represent what is actually seen of the strata in part of the line of cliff alluded to; the fainter lines, that portion which is

Fig. 64.

concealed beneath the sea level, as also that which is supposed to have once existed above the present surface.

We may still more easily illustrate the effects which a lateral thrust might produce on flexible strata, by placing several pieces of differently coloured cloths upon a table, and when they are spread out horizontally, cover them with a book. Then apply other books to each end, and force them towards each other. The folding of the cloths will exactly imitate those of the bent strata. (See fig. 65.)

Fig. 65.



Whether the analogous flexures in stratified rocks have really been due to similar sideway movements is a question of considerable difficulty. It will appear when the volcanic and granitic rocks are described that some of them have, when melted, been injected forcibly into fissures, while others, already in a solid state, have been protruded upwards through the incumbent crust of the earth, by which a great displacement of flexible strata must have been caused.

But we also know by the study of regions liable to earthquakes, that there are causes at work in the interior of the earth capable of producing a sinking in of the ground, sometimes very local, but sometimes extending over a wide area. The frequent repetition, or continuance throughout long periods, of such downward movements seems to imply the formation and renewal of cavities at a certain depth below the surface, whether by the removal of matter by volcanos and hot springs, or by the contraction of argillaceous rocks by heat and pressure, or any other combination of circumstances. Whatever conjectures we may indulge respecting the causes, it is certain that pliable beds may, in consequence of unequal degrees of subsidence, become folded to any amount, and have all the appearance of having been compressed suddenly by a lateral thrust.

The "Creeps," as they are called in coal-mines, afford an excellent illustration of this fact.—First, it may be stated generally, that the excavation of coal at a considerable depth causes the mass of overlying strata to sink down bodily, even when props are left to support the roof of the mine. "In Yorkshire," says Mr. Buddle, "three distinct subsidences were perceptible at the surface, after the clearing out of three seams of coal below, and innumerable vertical cracks were caused in the incumbent mass of sandstone and shale, which thus settled down."* The exact amount of depression in these cases

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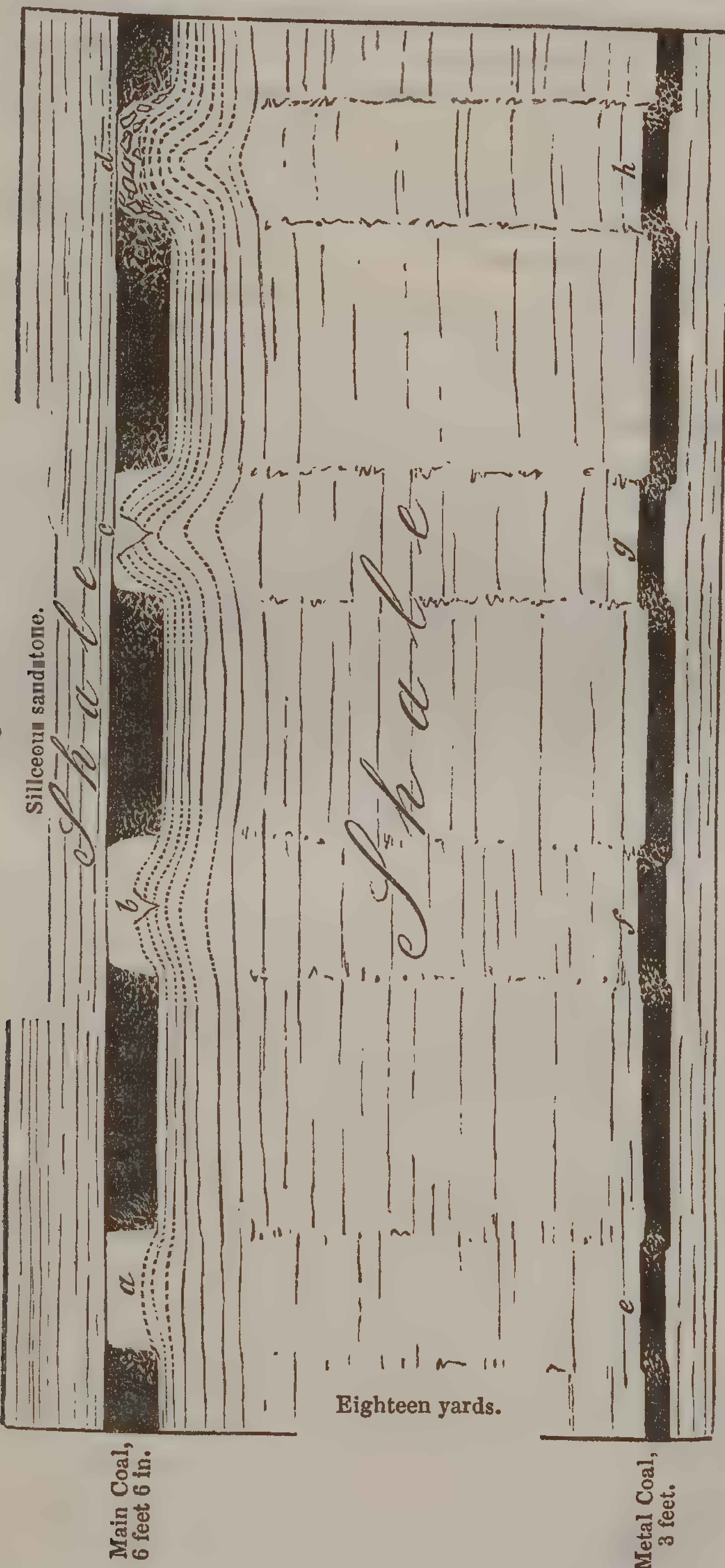
* Proceedings of Geol. Soc. vol. iii. p. 148.

can only be accurately measured where water accumulates on the surface, or a railway traverses a coal-field.

When a bed of coal is worked out, pillars or rectangular masses of coal are left at intervals as props to support the roof, and protect the colliers. Thus in fig. 66., representing a section at Wallsend, Newcastle, the galleries which have been excavated are represented by the white spaces *a b*, while the adjoining dark portions are parts of the original coal-seam left as props, beds of sandy clay or shale constituting the floor of the mine. When the props have been re-

Fig. 66.



Section of carboniferous strata, at Wallsend, Newcastle, showing "Creeps." (J. Buddle, Esq.)
Horizontal length of section 174 feet. The upper seam, or main coal, here worked out, was 630 feet below the surface.

duced in size, they are pressed down by the weight of overlying rocks (no less than 630 feet thick) upon the shale below, which is thereby squeezed and forced up into the open spaces.

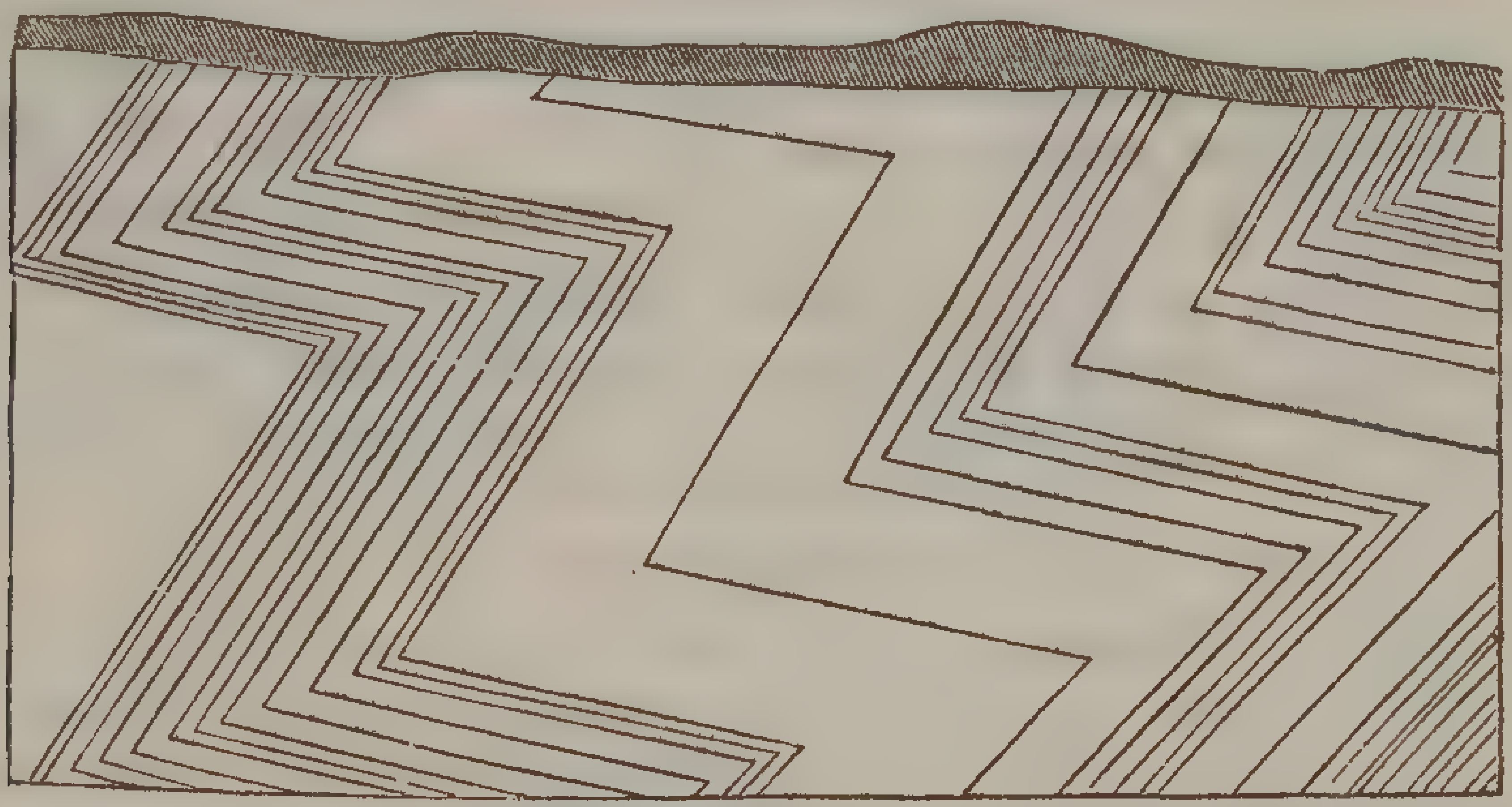
Now it might have been expected, that instead of the floor rising up, the ceiling would sink down, and this effect, called a "Thrust," does, in fact, take place where the pavement is more solid than the roof. But it usually happens, in coal-mines, that the roof is composed of hard shale, or occasionally of sandstone, more unyielding than the foundation, which often consists of clay. Even where the argillaceous substrata are hard at first, they soon become softened and reduced to a plastic state when exposed to the contact of air and water in the floor of a mine.

The first symptom of a "creep," says Mr. Buddle, is a slight curvature at the bottom of each gallery, as at *a*, fig. 66.: then the pavement continuing to rise, begins to open with a longitudinal crack, as at *b*: then the points of the fractured ridge reach the roof, as at *c*; and, lastly, the upraised beds close up the whole gallery, and the broken portions of the ridge are re-united and flattened at the top, exhibiting the flexure seen at *d*. Meanwhile the coal in the props has become crushed and cracked by pressure. It is also found that below the creeps *a*, *b*, *c*, *d*, an inferior stratum, called the "metal coal," which is 3 feet thick, has been fractured at the points *e*, *f*, *g*, *h*, and has risen, so as to prove that the upward movement, caused by the working out of the "main coal," has been propagated through a thickness of 54 feet of argillaceous beds, which intervene between the two coal seams. This same displacement has also been traced downwards more than 150 feet below the metal coal, but it grows continually less and less until it becomes imperceptible.

No part of the process above described is more deserving of our notice than the slowness with which the change in the arrangement of the beds is brought about. Days, months, or even years, will sometimes elapse between the first bending of the pavement and the time of its reaching the roof. Where the movement has been most rapid, the curvature of the beds is most regular, and the reunion of the fractured ends most complete; whereas the signs of displacement or violence are greatest in those creeps which have required months or years for their entire accomplishment. Hence we may conclude that similar changes may have been wrought on a larger scale in the earth's crust by partial and gradual subsidences, especially where the ground has been undermined throughout long periods of time; and we must be on our guard against inferring sudden violence, simply because the distortion of the beds is excessive.

Between the layers of shale, accompanying coal, we sometimes see the leaves of fossil ferns spread out as regularly as dried plants between sheets of paper in the herbarium of a botanist. These fern-leaves, or fronds, must have rested horizontally on soft mud, when first deposited. If, therefore, they and the layers of shale are now inclined, or standing on end, it is obviously the effect of subsequent derangement. The proof becomes, if possible, still more striking when these strata, including vegetable remains, are curved again and again, and even folded into the form of the letter Z, so that the same continuous layer of coal is cut through several times in the same perpendicular shaft. Thus, in the coal-field near Mons, in Belgium, these zigzag bendings are repeated four or five times, in the manner represented in fig. 67., the black lines representing seams of coal.*

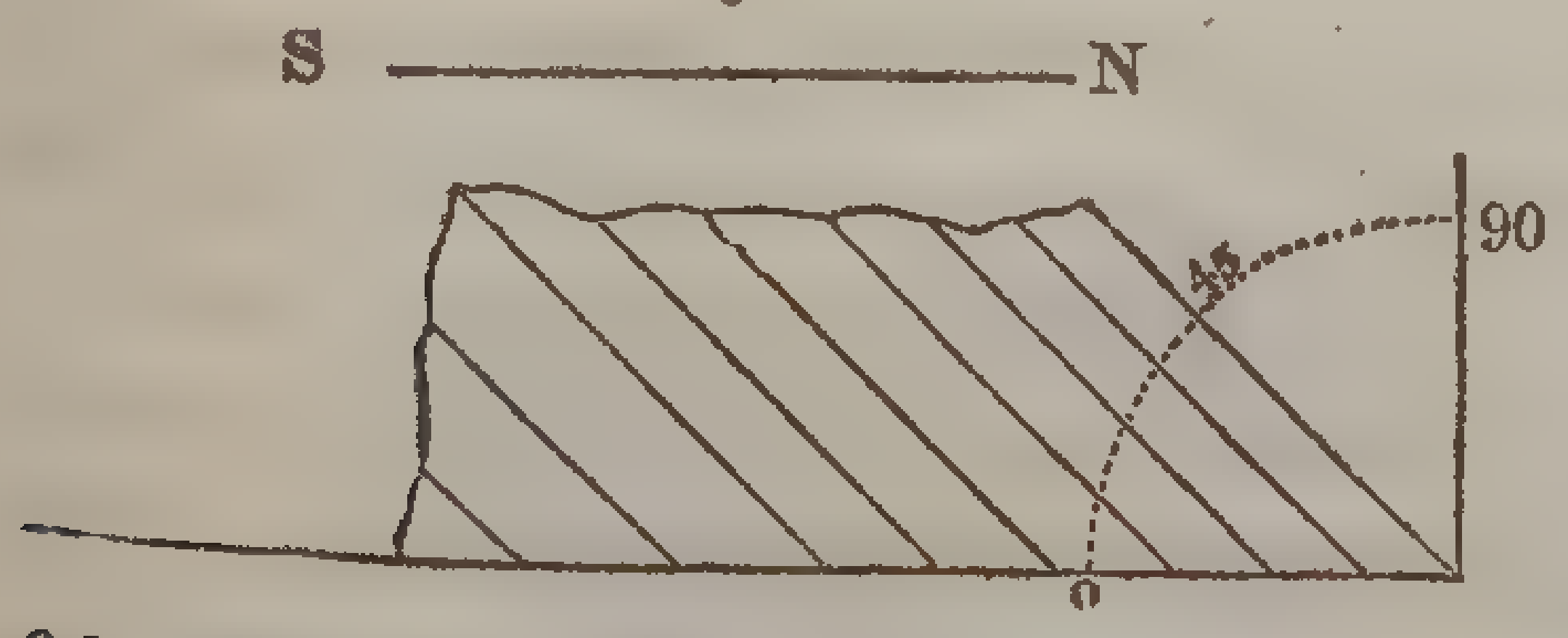
Fig. 67.



Zigzag flexures of coal near Mons.

Dip and Strike. — In the above remarks, several technical terms have been used, such as *dip*, the *unconformable position* of strata, and the *anticlinal* and *synclinal* lines, which, as well as the *strike* of the beds, I shall now explain. If a stratum or bed of rock, instead of being quite level, be inclined to one side, it is said to *dip;* the point of the compass to which it is inclined is called the *point of dip*, and the degree of deviation from a level or horizontal line is called *the amount of dip*, or *the angle of dip*. Thus, in the annexed diagram (fig. 68.), a series of strata are inclined, and they dip to the north at an angle of forty-five degrees. The *strike*, or *line of bearing*, is the prolongation or extension of the strata in a direction *at right angles* to the dip; and hence it is sometimes called the *direction* of the strata. Thus, in the above instance of strata dipping to the north, their strike must necessarily be east and west. We have borrowed the word from the German geologists, *streichen* signifying to extend, to have a certain direction. Dip and strike may be aptly illustrated by a row of houses running east and west, the long ridge of the roof representing the strike of the stratum of slates, which dip on one side to the north, and on the other to the south.

Fig. 68.



A stratum which is horizontal, or quite level in all directions, has neither dip nor strike.

It is always important for the geologist, who is endeavouring to comprehend the structure of a country, to learn how the beds dip in every part of the district; but it requires some practice to avoid being occasionally deceived, both as to the point of dip and the amount of it.

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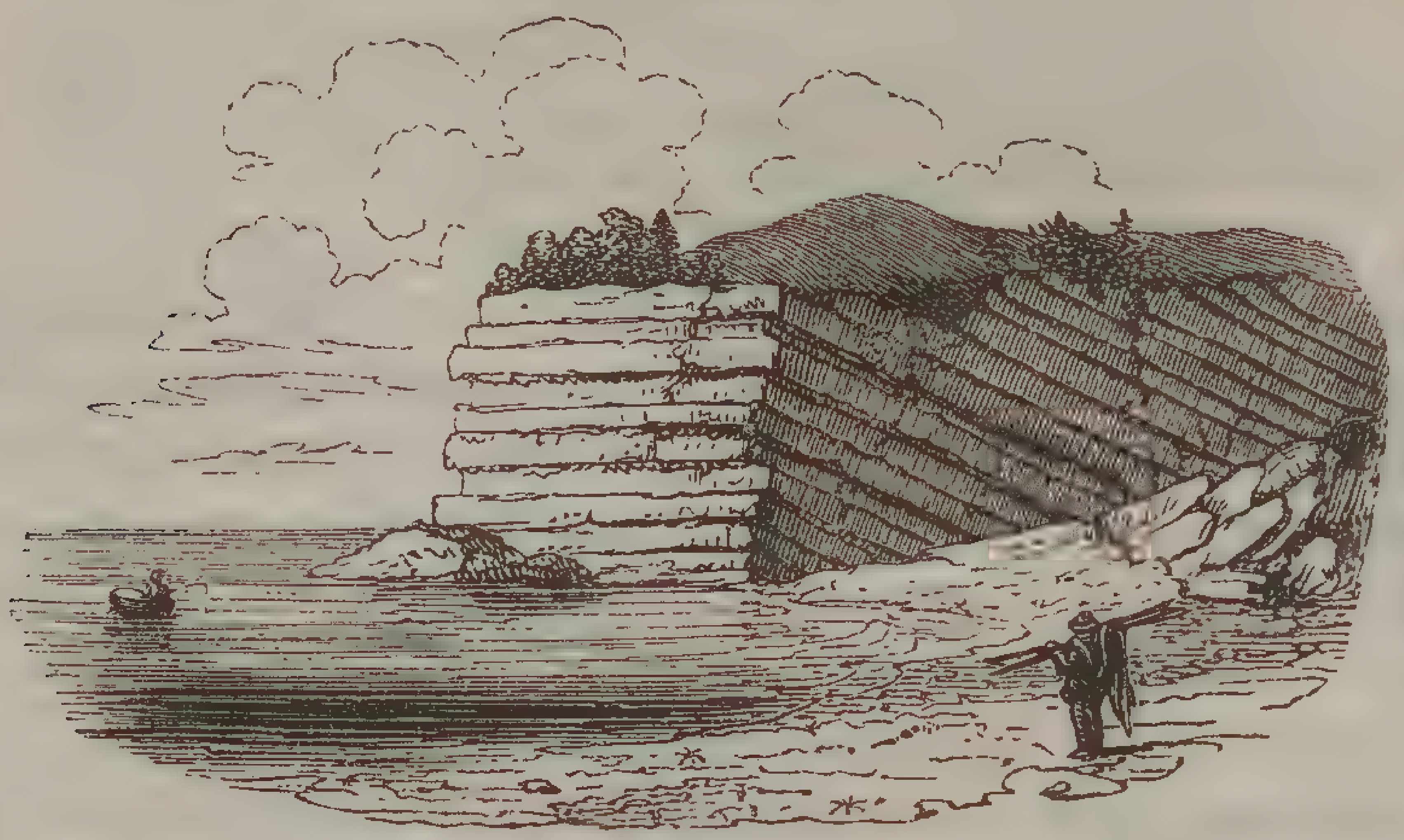
* See plan by M. Chevalier, Burat's D'Aubuisson, tom. ii. p. 334.

If the upper surface of a hard stony stratum be uncovered, whether artificially in a quarry, or by the waves at the foot of a cliff, it is easy to determine towards what point of the compass the slope is steepest, or in what direction water would flow, if poured upon it. This is the true dip. But the edges of highly inclined strata may give rise to perfectly horizontal lines in the face of a vertical cliff, if the observer see the strata in the line of their strike, the dip being inwards from the face of the cliff. If, however, we come to a break in the cliff, which exhibits a section exactly at right angles to the line of the strike, we are then able to ascertain the true dip. In the annexed drawing (fig. 69.), we may suppose a headland, one side of which faces to the north, where the beds would appear perfectly horizontal to a person in the boat; while in the other side facing the west, the true dip would be seen by the person on shore to be at an angle of 40°. If, therefore, our observations are confined to a vertical precipice facing in one direction, we must endeavour to find a ledge or portion of the plane of one of the beds projecting beyond the others, in order to ascertain the true dip.

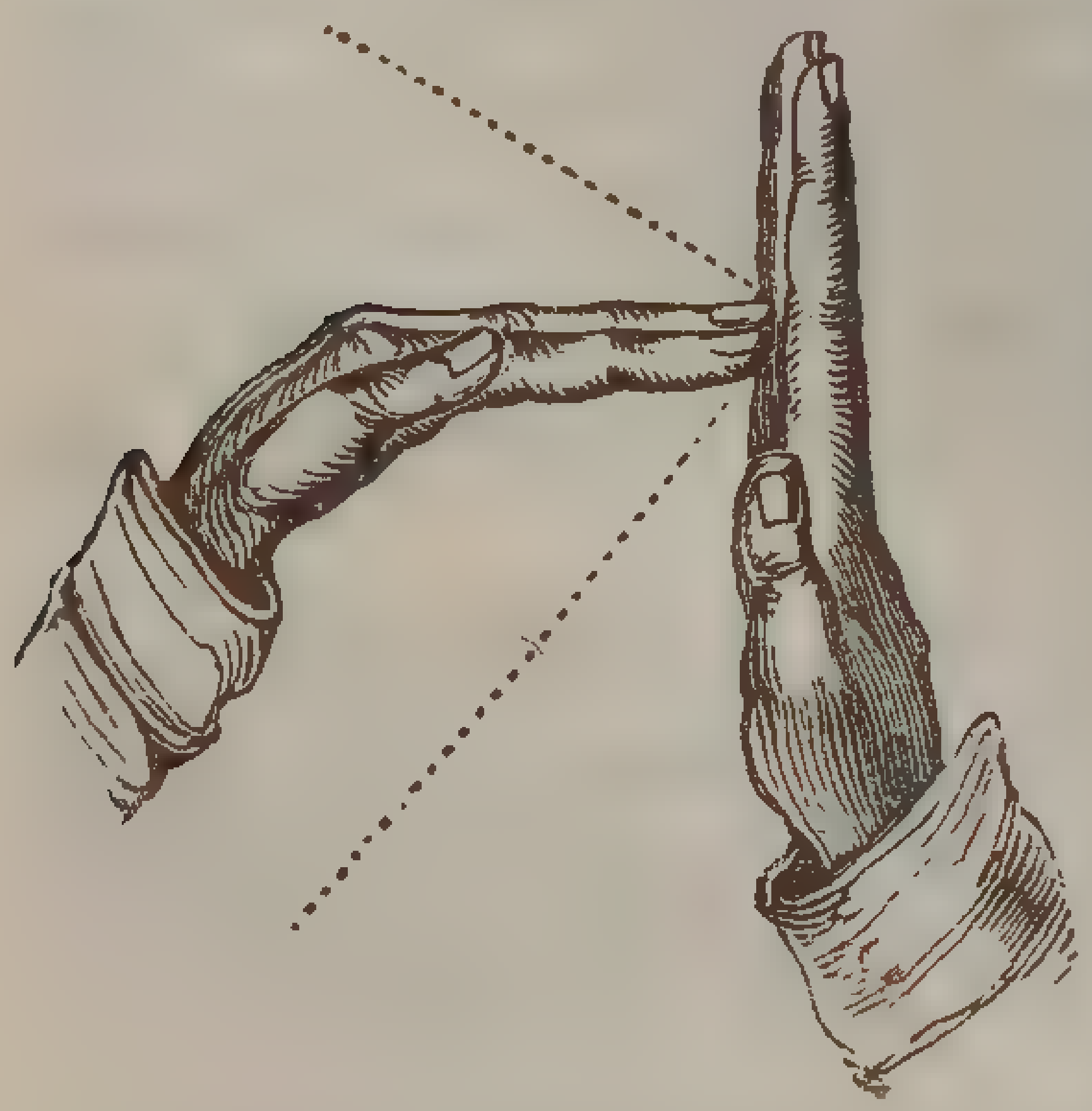
Fig. 69.



Apparent horizontality of inclined strata.

It is rarely important to determine the angle of inclination with such minuteness as to require the aid of the instrument called a clinometer. We may measure the angle within a few degrees by standing exactly opposite to a cliff where the true dip is exhibited, holding the hands immediately before the eyes, and placing the fingers of one in a perpendicular, and of the other in a horizontal position, as in fig. 70. It is thus easy to discover whether the lines of the inclined beds bisect the angle of 90°, formed by the meeting of the hands, so as to give an angle of 45°, or whether it would divide the space into two equal or unequal portions. The upper dotted line may express a stratum dipping to the north; but should the beds dip precisely to the opposite point of

Fig. 70.



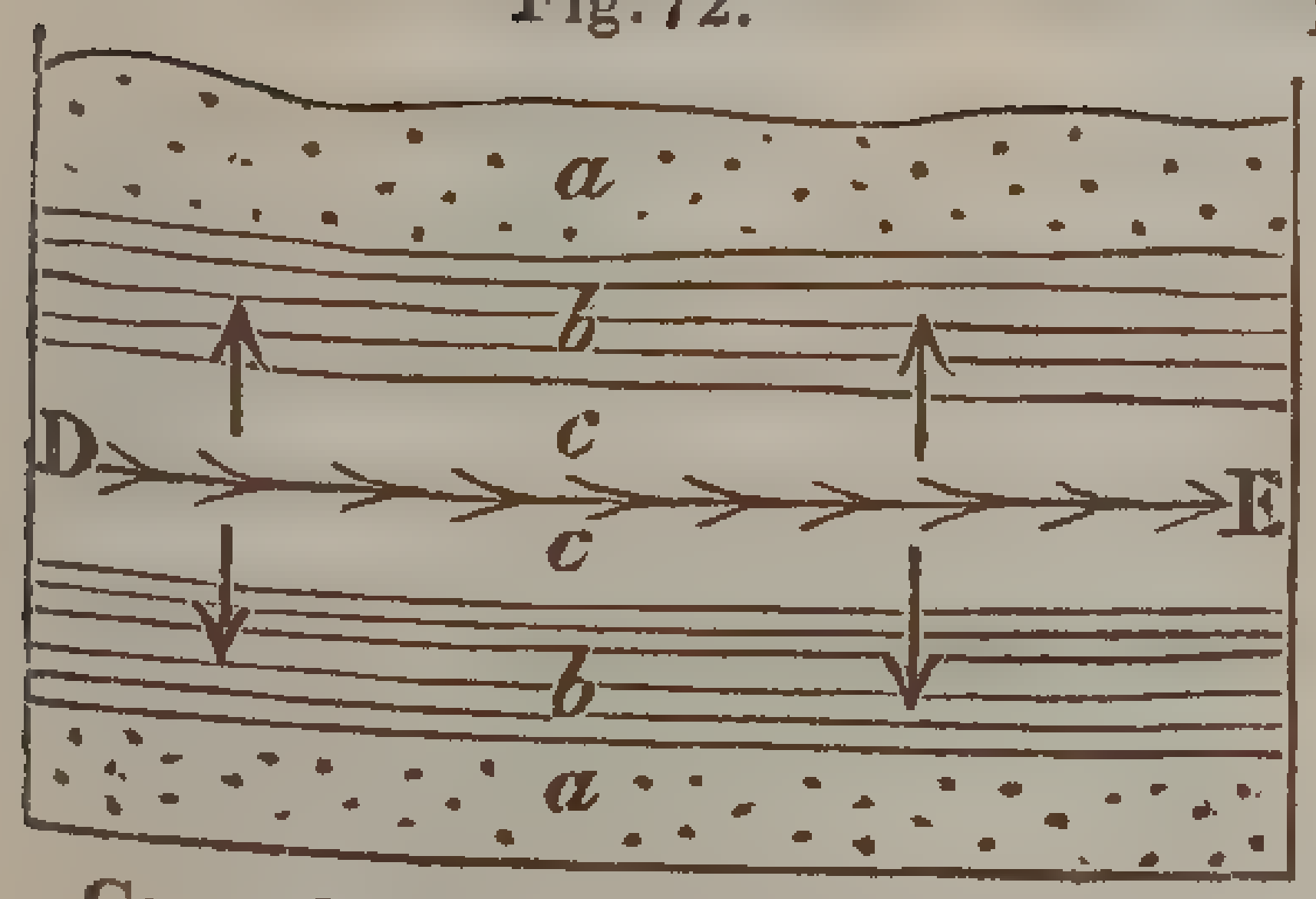
the compass as in the lower dotted line, it will be seen that the amount of inclination may still be measured by the hands with equal facility.

It has been already seen, in describing the curved strata on the east coast of Scotland, in Forfarshire and Berwickshire, that a series of concave and convex bendings are occasionally repeated several times. These usually form part of a series of parallel waves of strata, which are prolonged in the same direction throughout a considerable extent of country. Thus, for example, in the Swiss Jura, that lofty chain of mountains has been proved to consist of many parallel ridges, with intervening longitudinal valleys, as in fig. 71., the ridges being formed by curved fossiliferous strata, of which the nature and dip are occasionally displayed in deep transverse gorges, called "cluses," caused by fractures at right angles to the direction of the chain.* Now let us suppose these ridges and parallel valleys to run north and south, we should then say that the *strike* of the beds is north and south, and the *dip* east and west. Lines drawn along the summits of the ridges, A, B, would be anticlinal lines, and one following the bottom of the adjoining valleys a synclinal line. It will be observed that some of these ridges, A, B, are unbroken on the summit, whereas one of them, C, has been fractured along the line of strike, and a portion of it carried away by denudation, so that the ridges of the beds in the formations *a*, *b*, *c*, come out to the day, or, as the miners say, *crop out*, on the sides of a valley. The ground plan of such a denuded ridge as C, as given in a geological map, may be expressed by the diagram fig. 72., and the cross section of the same by fig. 73. The line D E, fig. 72., is the anticlinal line, on each side

Fig. 71.

Section illustrating the structure of the Swiss Jura.

Fig. 72.



Ground plan of the denuded ridge C, fig. 71.

Fig. 73.

Transverse section.

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* See M. Thurmann's work, "Essai sur les Soulèvemens Jurassiques du Porrentruy, Paris, 1832," with whom I examined part of these mountains in 1835.

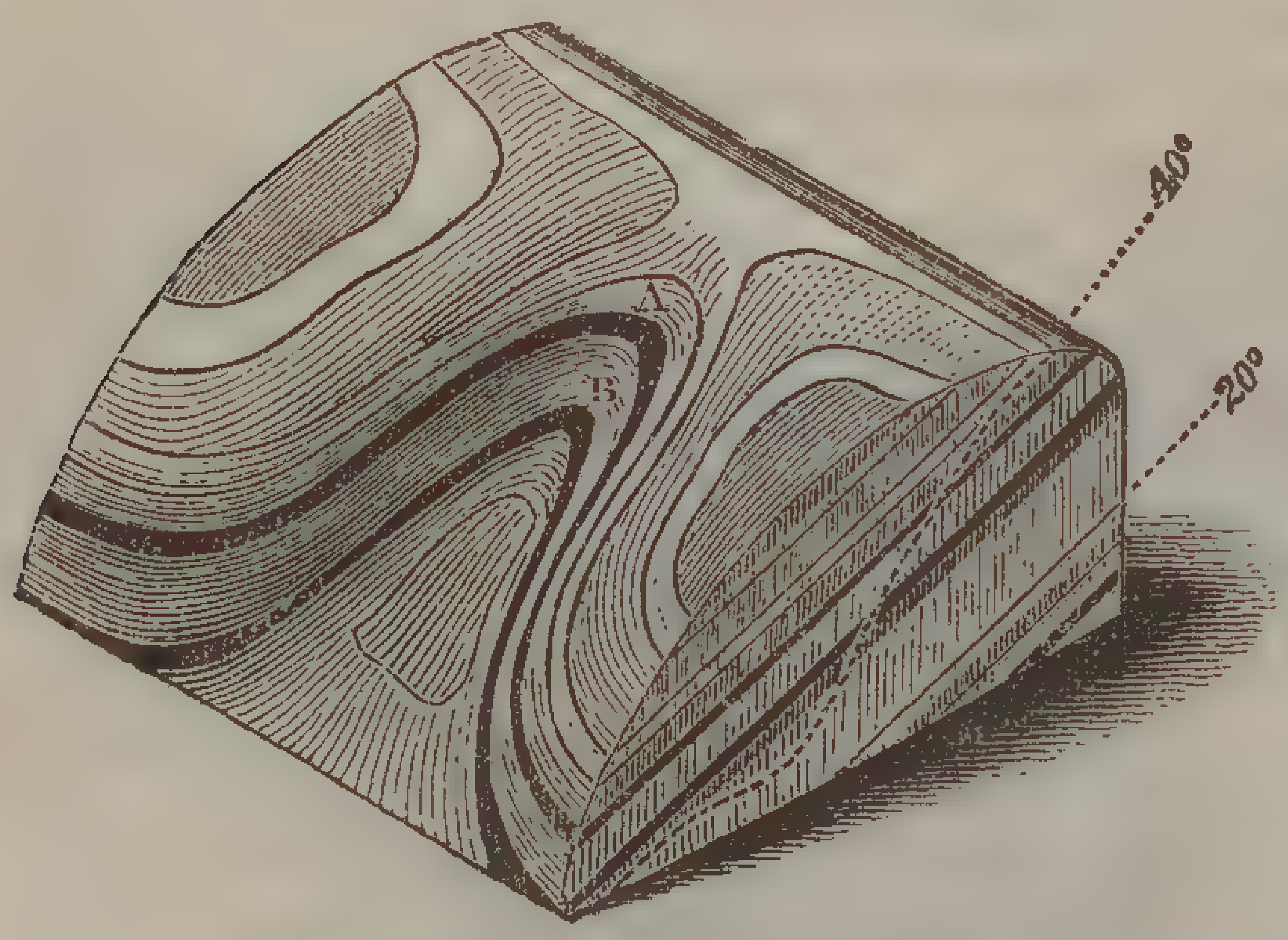
of which the dip is in opposite directions, as expressed by the arrows. The emergence of strata at the surface is called by miners their *out-crop* or *basset*.

If, instead of being folded into parallel ridges, the beds form a boss or dome-shaped protuberance, and if we suppose the summit of the dome carried off, the ground plan would exhibit the edges of the strata forming a succession of circles, or ellipses, round a common centre. These circles are the lines of strike, and the dip being always at right angles is inclined in the course of the circuit to every point of the compass, constituting what is termed a qua-quaversal dip — that is, turning each way.

There are endless variations in the figures described by the basset-edges of the strata, according to the different inclination of the beds, and the mode in which they happen to have been denuded. One of the simplest rules with which every geologist should be acquainted, relates to the V-like form of the beds as they crop out in an ordinary valley. First, if the strata be horizontal, the V-like form will be also on a level, and the newest strata will appear at the greatest heights.

Secondly, if the beds be inclined and intersected by a valley sloping in the same direction, and the dip of the beds be less steep than the slope of the valley, then the V's, as they are often termed by miners, will point upwards (see fig. 74.), those formed by the newer beds appearing in a superior position, and extending highest up the valley, as A is seen above B.

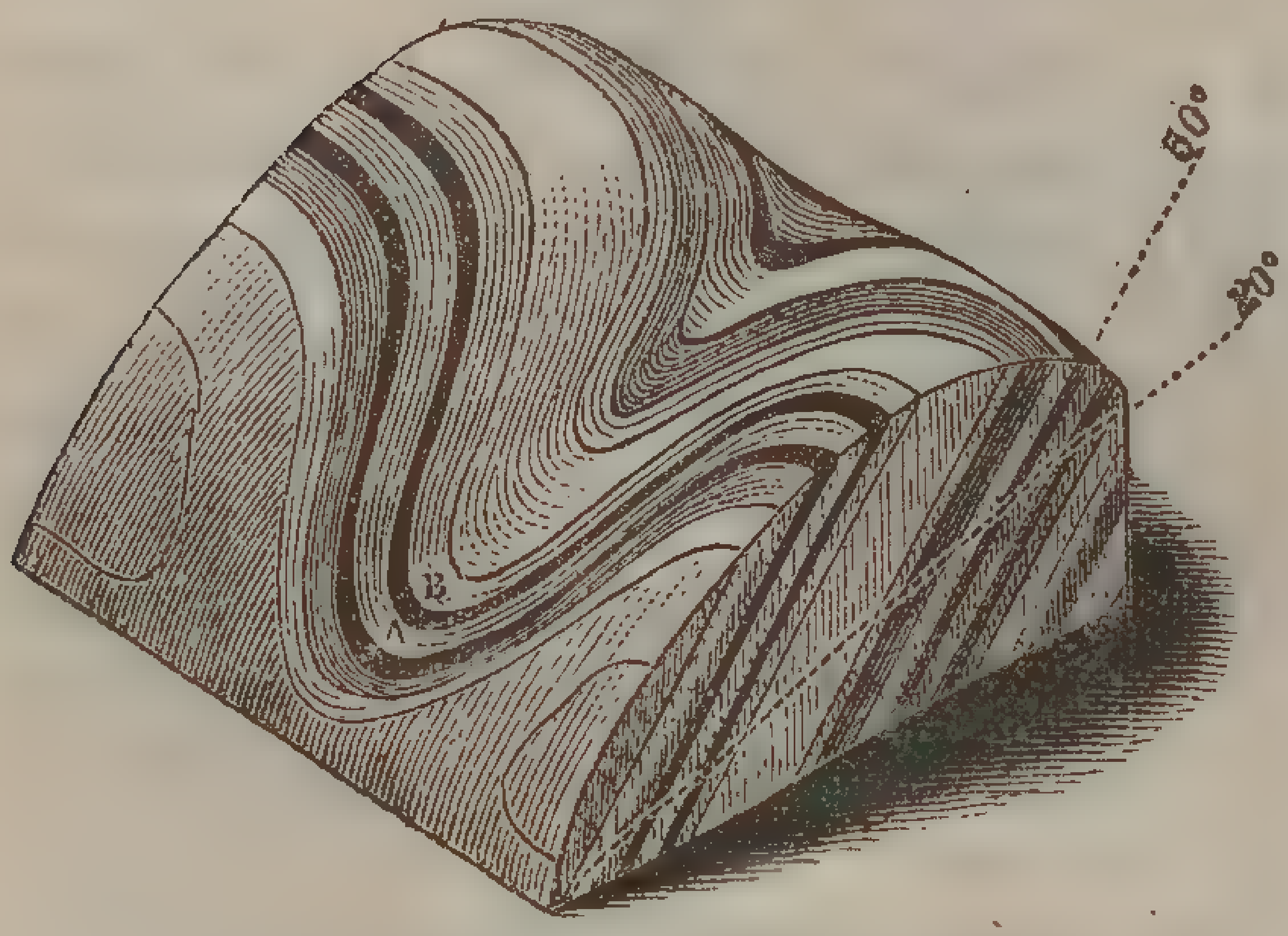
Fig. 74.



Slope of valley 40°, dip of strata 20°.

Thirdly, if the dip of the beds be steeper than the slope of the valley, then the V's will point downwards (see fig. 75.), and those formed of the older beds will now appear uppermost, as B appears above A.

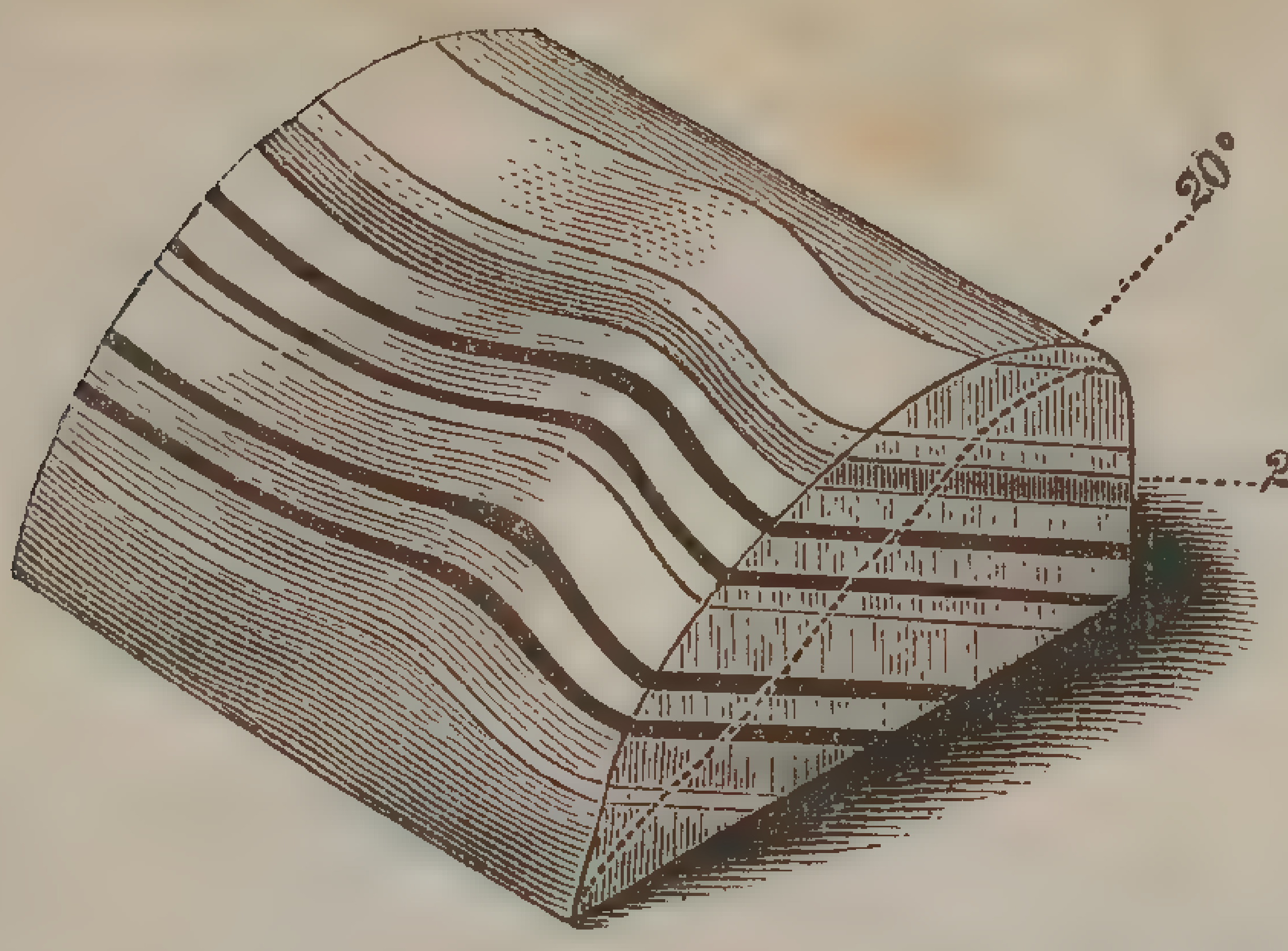
Fig. 75



Slope of valley 20°, dip of strata 50°.

Fourthly, in every case where the strata dip in a contrary direction to the slope of the valley, whatever be the angle of inclination, the newer beds will appear the highest, as in the first and second cases. This is shown by the drawing (fig. 76.), which exhibits strata rising at an angle of 20°,

Fig. 76.



Slope of valley 20°, dip of strata 20°, in opposite directions.

and crossed by a valley, which declines in an opposite direction at 20°.*

These rules may often be of great practical utility; for the different degrees of dip occurring in the two cases represented in figures 74 and 75. may occasionally be encountered in following the same line of flexure at points a few miles distant from each other. A miner unacquainted with the rule, who had first explored the valley (fig. 74.), may have sunk a vertical shaft below the coal seam A, until he reached the inferior bed B. He might then pass to the valley fig. 75., and discovering there also the outcrop of two coal seams, might begin his workings in the uppermost in the expectation of coming down to the other bed A, which would be observed cropping out lower down the valley. But a glance at the section will demonstrate the futility of such hopes.

In the majority of cases, an anticlinal axis forms a ridge, and a synclinal axis a valley, as in A, B, fig. 62. p. 48.; but there are exceptions to this rule, the beds sometimes sloping inwards from either side of a mountain, as in fig. 77.

Fig. 77.

On following one of the anticlinal ridges of the Jura, before mentioned, A, B, C, fig. 71., we often discover longitudinal cracks and sometimes large fissures along the line where the flexure was greatest. Some of these, as above stated, have been enlarged by denudation into valleys of considerable width, as at C, fig. 71., which follow the line of strike, and which we may suppose to have been hollowed out at the time when these rocks were still beneath the level of the sea, or perhaps at the period of their gradual emergence from beneath the waters. The existence of such cracks at the point of the sharpest bending of solid strata of limestone is precisely what we should have expected; but the occasional want of all similar signs of fracture, even where the strain has been greatest, as at *a*, fig. 71., is not always easy to explain. We must imagine that many strata of limestone, chert, and other rocks which are now brittle, were pliant when bent into their present position.

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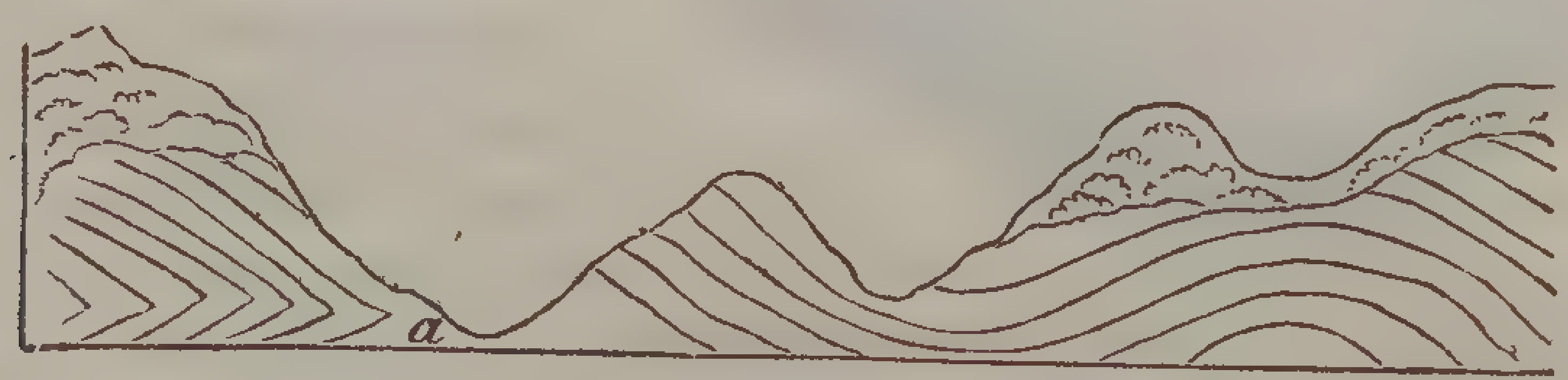
* I am indebted to the kindness of T. Sopwith, Esq., for three models which I have copied in the above diagrams; but the beginner may find it by no means easy to understand such copies, although, if he were to examine and handle the originals, turning them about in different ways, he would at once comprehend their meaning as well as the import of others far more complicated, which the same engineer has constructed to illustrate *faults*.

They may have owed their flexibility in part to the fluid matter which they contained in their minute pores, as before described (p. 35.), and in part to the permeation of sea-water while they were yet submerged.

At the western extremity of the Pyrenees, great curvatures of the strata are seen in the sea cliffs, where the rocks consist of marl, grit, and chert. At certain points, as at *a*, fig. 78., some of the bendings of the flinty chert are so sharp, that specimens might be broken off, well fitted to serve as ridge-tiles on the roof of a house. Although this chert could not have been brittle as now, when first folded into this shape, it presents, nevertheless, here and there at the points of greatest flexure small cracks, which show that it was solid, and not wholly incapable of breaking at the period of its displacement. The numerous rents alluded to are not empty, but filled with calcedony and quartz.

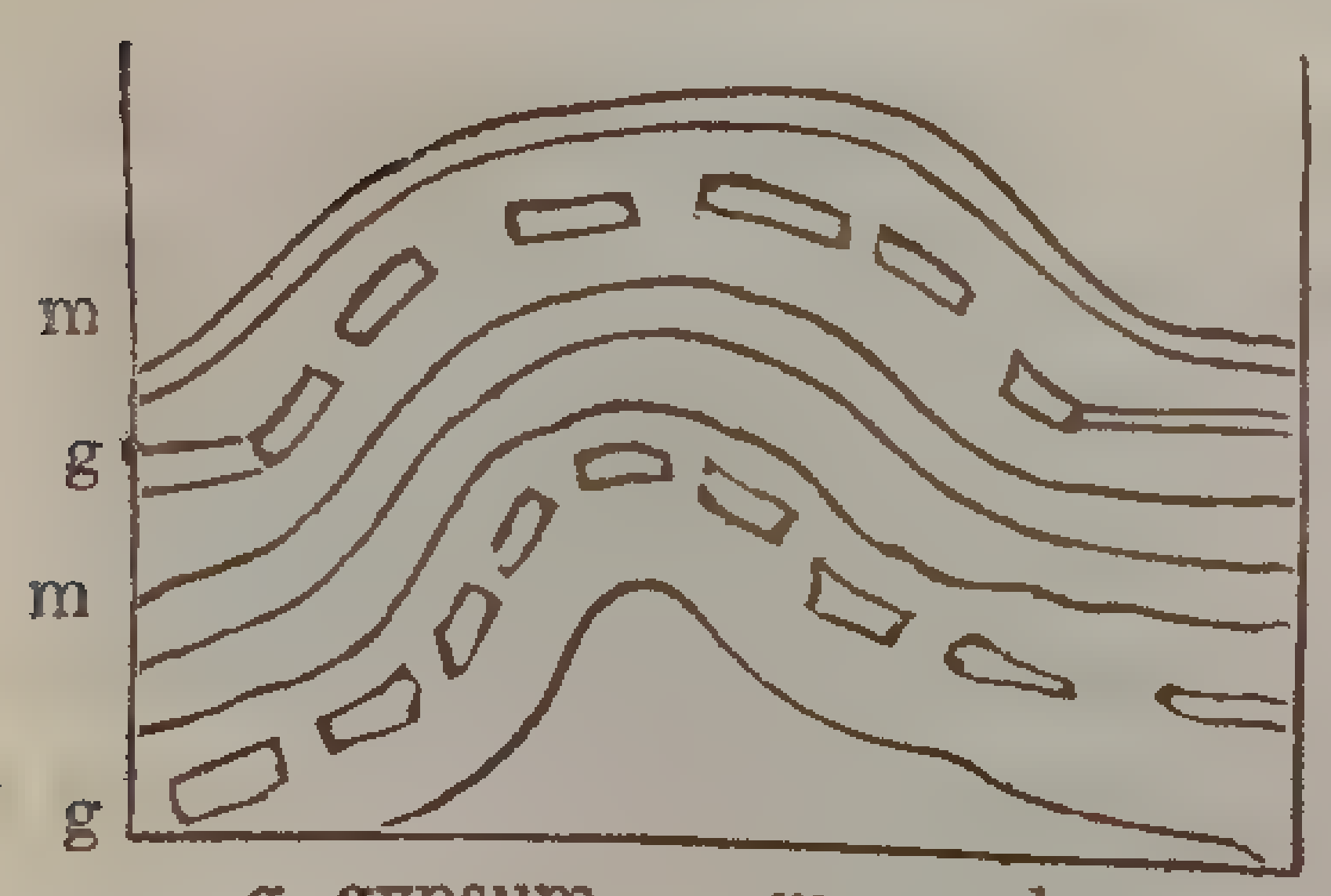
Fig. 78.



Strata of chert, grit, and marl, near St. Jean de Luz.

Between San Caterina and Castrogiovanni, in Sicily, bent and undulating gypseous marls occur, with here and there thin beds of solid gypsum interstratified. Sometimes these solid layers have been broken into detached fragments, still preserving their sharp edges (*g g*, fig. 79.), while the continuity of the more pliable and ductile marls, *m m*, has not been interrupted.

Fig. 79.



g. gypsum. *m*. marl.

I shall conclude my remarks on bent strata by stating, that, in mountainous regions like the Alps, it is often difficult for an experienced geologist to determine correctly the relative age of beds by superposition, so often have the strata been folded back upon themselves, the upper parts of the curve having been removed by denudation. Thus, if we met with the strata seen in the section fig. 80., we should naturally suppose that there were twelve distinct beds, or sets of beds, No. 1. being the newest, and No. 12. the oldest of the series. But this section may, perhaps, exhibit merely six beds, which have been folded in the manner seen in fig. 81., so that each of them is twice repeated, the position of one half being reversed, and part of No. 1., originally the uppermost, having now become the lowest of the series. These phenomena are often observable on a magnificent scale in certain regions in Switzerland in precipices from 2000 to 3000 feet in perpendicular height.

Fig. 80.

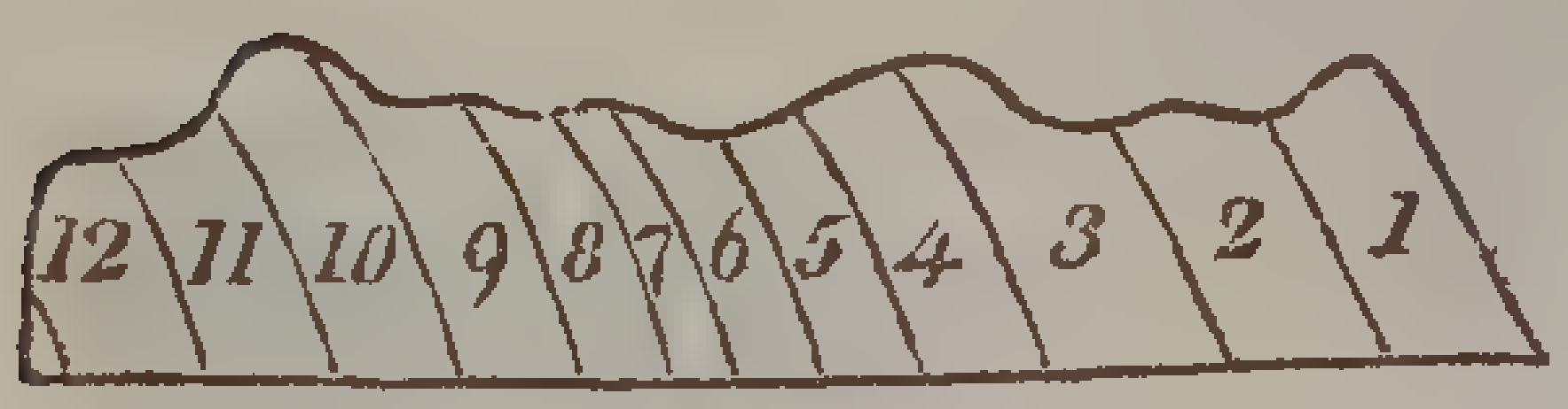
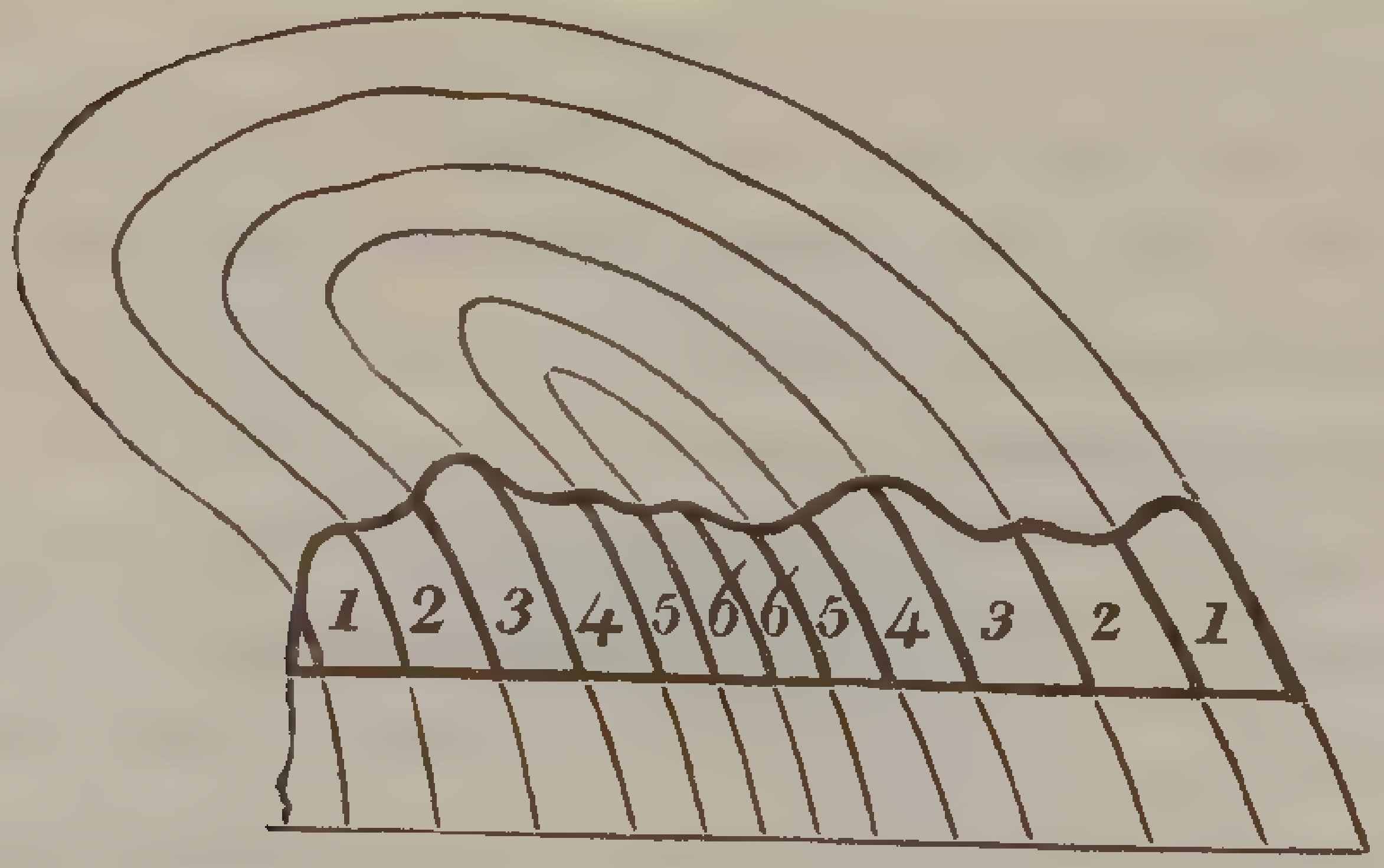
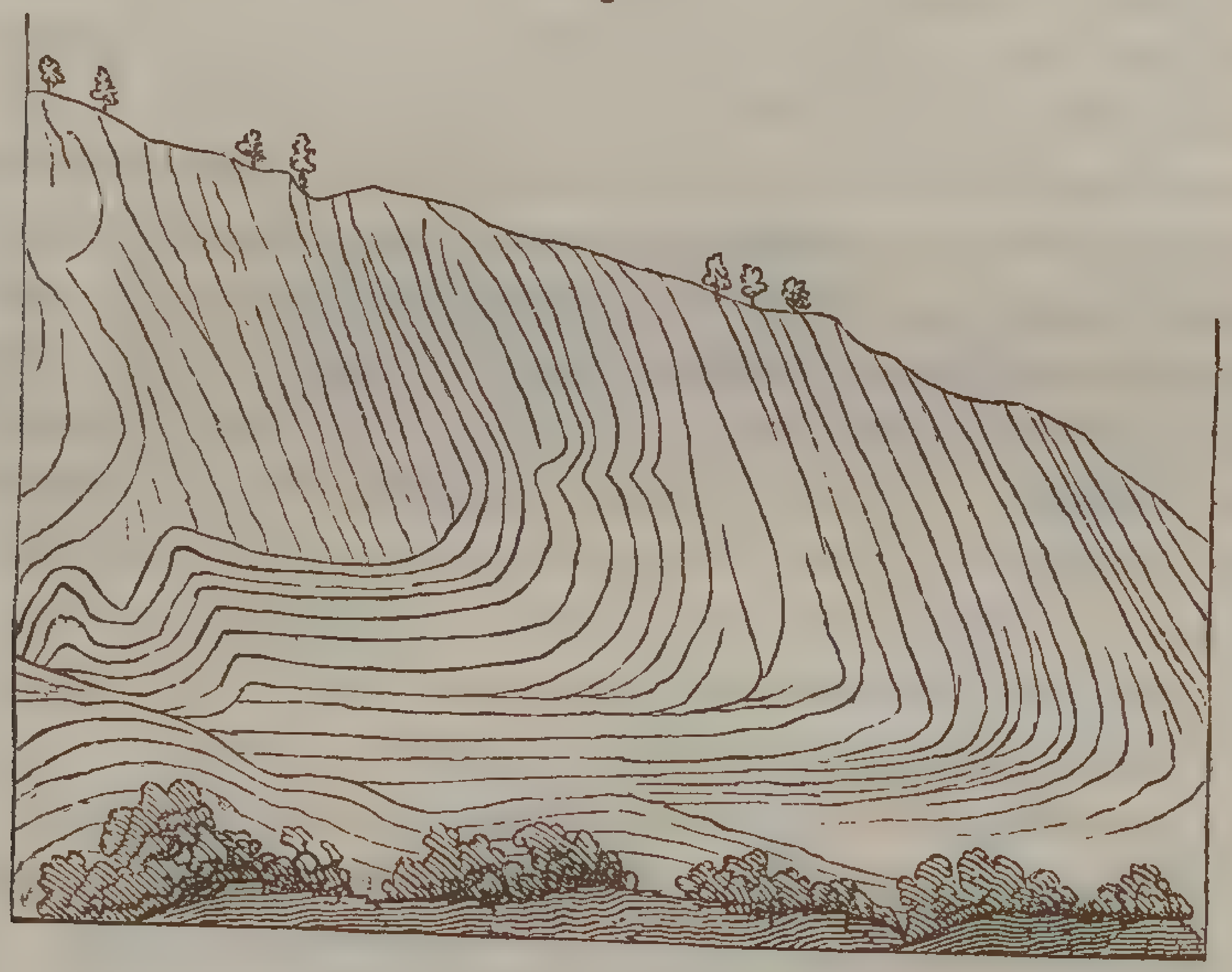


Fig. 81.



In the Iselten Alp, in the valley of the Lutschine, between Unterseen and Grindelwald, curves of calcareous shale are seen from 1000 to 1500 feet in height, in which the beds sometimes plunge down vertically for a depth of 1000 feet and more, before they bend round again. There are many flexures not inferior in dimensions in the Pyrenees, as those near Gavarnie, at the base of Mont Perdu.

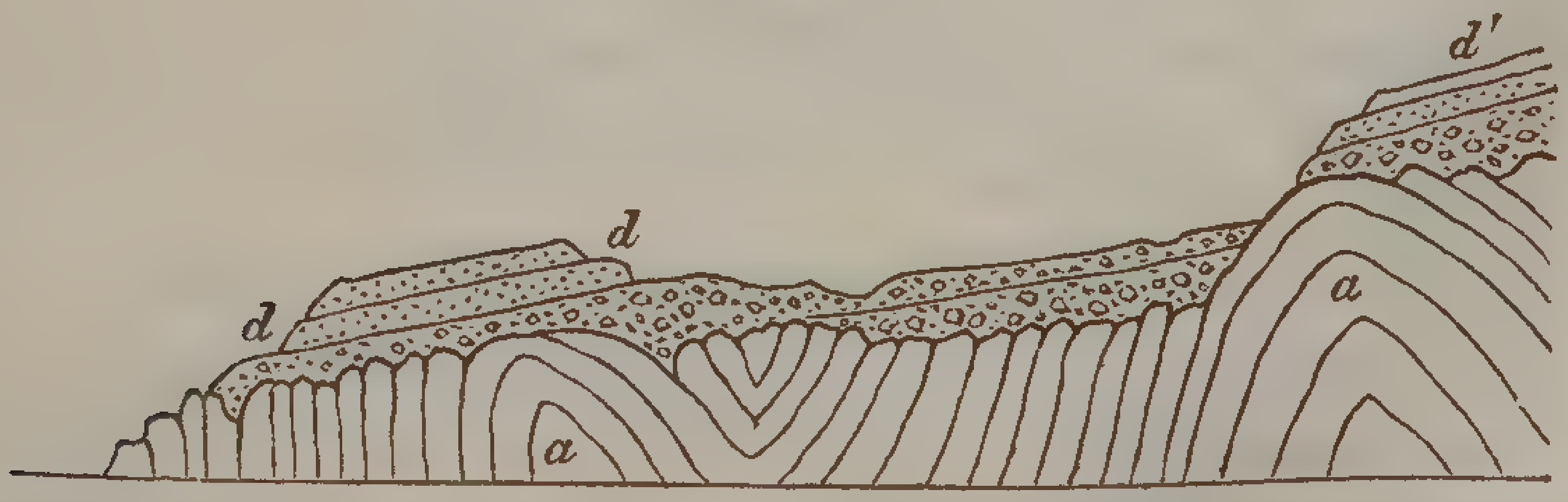
Fig. 82.



Curved strata of the Iselten Alp.

Unconformable stratification. — Strata are said to be unconformable, when one series is so placed over another, that the planes of the superior repose on the edges of the inferior (see fig. 83.). In this case it is evident that a period had elapsed between the production of the two sets of strata, and that, during this interval, the older

Fig. 83.



Unconformable junction of old red sandstone and Silurian schist at the Siccar Point, near St. Abb's Head, Berwickshire. See also Frontispiece.

series had been tilted and disturbed. Afterwards the upper series was thrown down in horizontal strata upon it. If these superior beds, as *d*, *d*, fig. 83., are also inclined, it is plain that the lower strata, *a*, *a*, have been twice displaced; first, before the deposition of the newer beds, *d*, *d*, and a second time when these same strata were thrown out of the horizontal position.

Playfair has remarked * that this kind of junction which we now call unconformable had been described before the time of Hutton, but that he was the first geologist who appreciated its importance, as illustrating the high antiquity and great revolutions of the globe. He had observed that where such contacts occur, the lowest beds of the newer series very generally consist of a breccia or conglomerate consisting of angular and rounded fragments, derived from the breaking up of the more ancient rocks. On one occasion the Scotch geologist took his two distinguished pupils, Playfair and Sir James Hall, to the cliffs on the east coast of Scotland, near the village of Eyemouth, not far from St. Abb's Head, where the schists of the Lammermuir range are undermined and dissected by the sea. Here the curved and vertical strata, now known to be of Silurian age, and which often exhibit a ripple-marked surface, are well exposed at the headland called the Siccar Point, penetrating with their edges into the incumbent beds of slightly inclined sandstone, in which large pieces of the schist, some round and others angular, are united by an arenaceous cement. "What clearer evidence," exclaims Playfair, "could we have had of the different formation of these rocks, and of the long interval which separated their formation, had we actually seen them emerging from the bosom of the deep? We felt ourselves necessarily carried back to the time when the schistus on which we stood was yet at the bottom of the sea, and when the sandstone before us was only beginning to be deposited in the shape of sand or mud, from the waters of a superincumbent ocean. An epoch still more remote presented itself, when even the most ancient of these rocks, instead of standing upright in vertical beds, lay in horizontal planes at the bottom of the sea, and was not yet disturbed by that immeasurable force which has burst asunder the solid pavement of the globe. Revolutions still more remote appeared in the distance of this extraordinary perspective. The mind seemed to grow giddy by looking so far into the abyss of time; and while we listened with earnestness and admiration to the philosopher who was now unfolding to us the order and series of these wonderful events, we became sensible how much farther reason may sometimes go than imagination can venture to follow." †

In the frontispiece of this volume the reader will see a view of this classical spot, reduced from a large picture, faithfully drawn and coloured from nature by the youngest son of the late Sir James Hall. It was impossible, however, to do justice to the original sketch, in an

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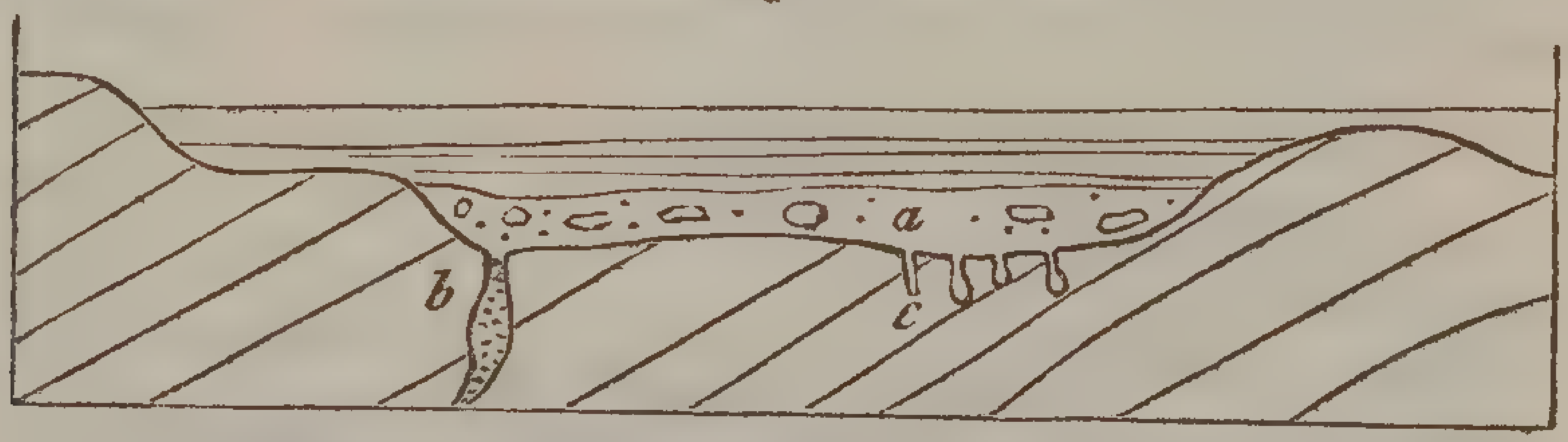
* Biographical account of Dr. Hutton.

† Playfair, ibid.; see his Works, Edin. 1822, vol. iv. p. 81.

engraving, as the contrast of the red sandstone and the light fawn-coloured vertical schists could not be expressed. From the point of view here selected, the underlying beds of the perpendicular schist, *a*, are visible at *b* through a small opening in the fractured beds of the covering of red sandstone, *d d*, while on the vertical face of the old schist at *a′ a″* a conspicuous ripple-mark is displayed.

It often happens that in the interval between the deposition of two sets of unconformable strata, the inferior rock has not only been denuded, but drilled by perforating shells. Thus, for example, at Autreppe and Gusigny, near Mons, beds of an ancient (primary or paleozoic) limestone, highly inclined, and often bent, are covered with horizontal strata of greenish and whitish marls of the Cretaceous formation. The lowest and therefore the oldest bed of the horizontal series is usually the sand and conglomerate, *a*, in which are rounded fragments of stone, from an inch to two feet in diameter. These fragments have often adhering shells attached to them, and have been bored by perforating mollusca. The solid surface of the inferior limestone has also been bored, so as to exhibit cylindrical and pear-shaped cavities, as at *c*, the work of saxicavous mollusca; and many rents, as at *b*, which descend several feet or yards into the limestone, have been filled with sand and shells, similar to those in the stratum *a*.

Fig. 84.

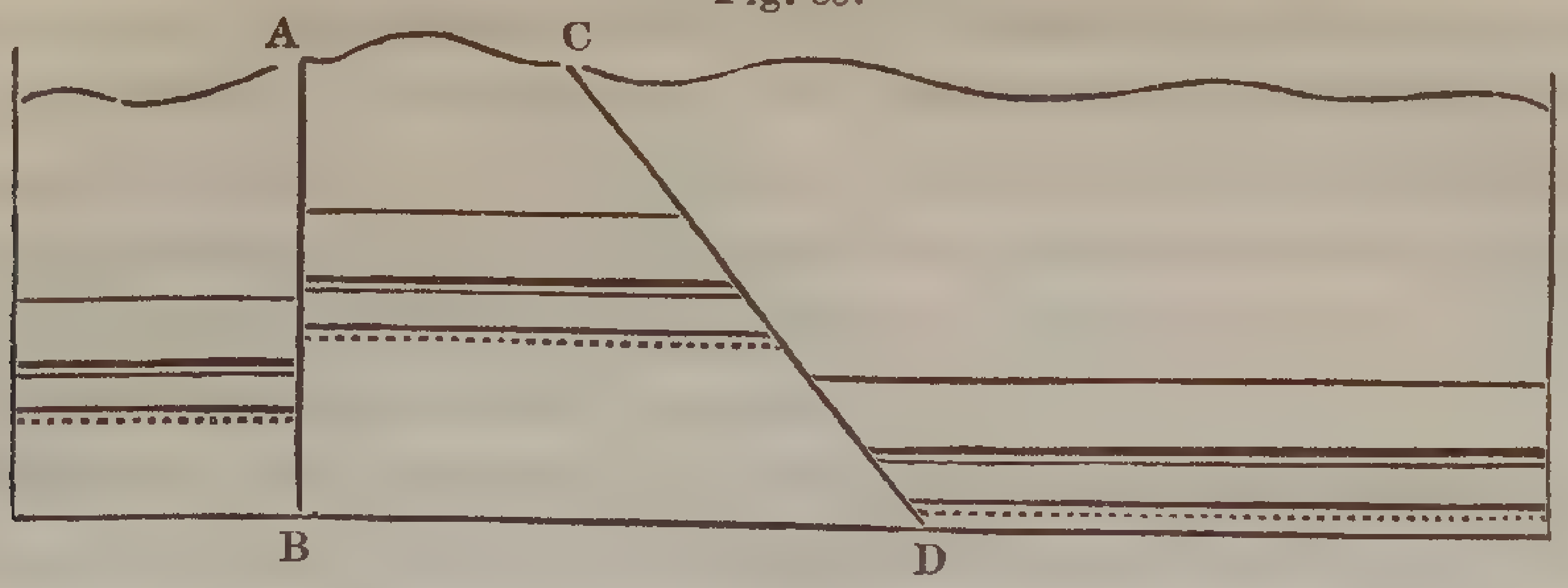


Junction of unconformable strata near Mons, in Belgium.

Fractures of the strata and faults.—Numerous rents may often be seen in rocks which appear to have been simply broken, the separated parts remaining in the same places; but we often find a fissure, several inches or yards wide, intervening between the disunited portions. These fissures are usually filled with fine earth and sand, or with angular fragments of stone, evidently derived from the fracture of the contiguous rocks.

It is not uncommon to find the mass of rock, on one side of a fissure thrown up above or down below the mass with which it was once in contact on the other side. "This mode of displacement is called a shift, slip, or fault. "The miner," says Playfair, describing a fault, "is often perplexed, in his subterraneous journey, by a derangement in the strata, which changes at once all those lines and bearings which had hitherto directed his course. When his mine reaches a certain plane, which is sometimes perpendicular, as in A B, fig. 85., sometimes oblique to the horizon (as in C D, ibid.), he finds the beds of rock broken asunder, those on the one side of the plane having changed their place, by sliding in a particular direction along the face of the others. In this motion they have sometimes preserved their parallelism, as in fig. 85., so that the strata on each side of the

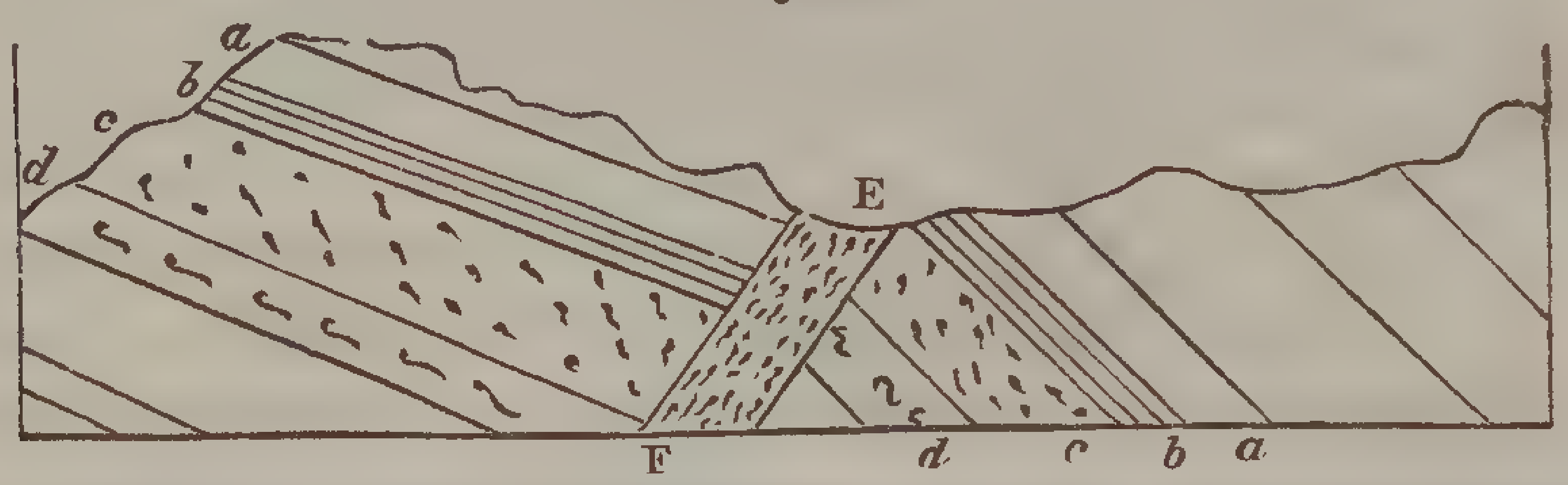
Fig. 85.



Faults. A B perpendicular, C D oblique to the horizon.

faults A B, C D, continue parallel to one another; in other cases, the strata on each side are inclined, as in *a*, *b*, *c*, *d* (fig. 86.), though

Fig. 86.



E F, fault or fissure filled with rubbish, on each side of which the shifted strata are not parallel.

their identity is still to be recognized by their possessing the same thickness and the same internal characters."*

In Coalbrook Dale, says Mr. Prestwich †, deposits of sandstone, shale, and coal, several thousand feet thick, and occupying an area of many miles, have been shivered into fragments, and the broken remnants have been placed in very discordant positions, often at levels differing several hundred feet from each other. The sides of the faults, when perpendicular, are commonly separated several yards, but are sometimes as much as 50 yards asunder, the interval being filled with broken *débris* of the strata. In following the course of the same fault it is sometimes found to produce in different places very unequal changes of level, the amount of shift being in one place 300, and in another 700 feet, which arises, in some cases, from the union of two or more faults. In other words, the disjointed strata have in certain districts been subjected to renewed movements, which they have not suffered elsewhere.

We may occasionally see exact counterparts of these slips, on a small scale, in pits of loose sand and gravel, many of which have doubtless been caused by the drying and shrinking of argillaceous and other beds, slight subsidences having taken place from failure of support. Sometimes, however, even these small slips may have been produced during earthquakes; for land has been moved, and its level, relatively to the sea, considerably altered, within the period when much of the alluvial sand and gravel now covering the surface of continents was deposited.

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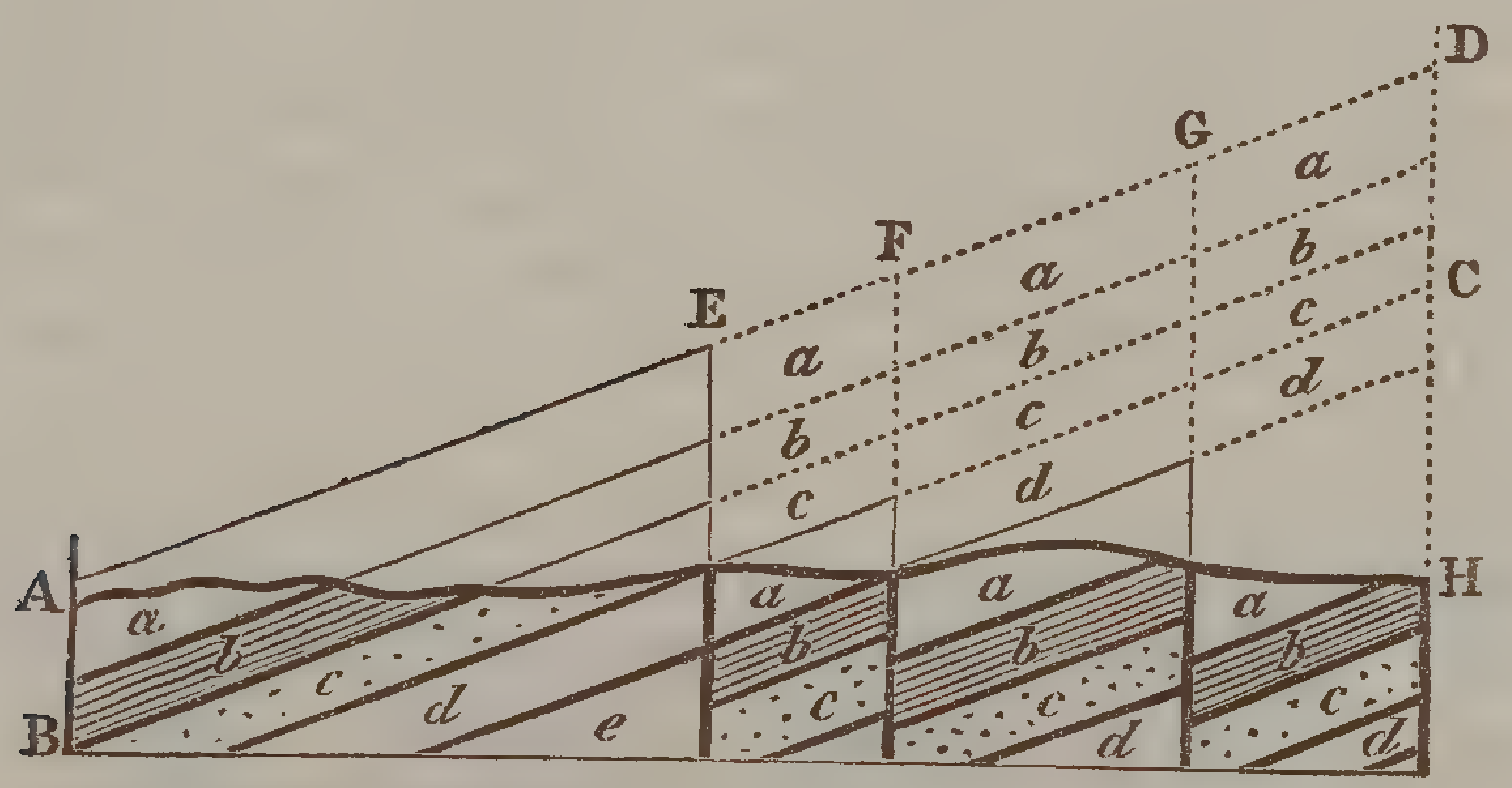
* Playfair, Illust. of Hutt. Theory, § 42.

† Geol. Trans. second series, vol. v. p. 452.

I have already stated that a geologist must be on his guard, in a region of disturbed strata, against inferring repeated alternations of rocks, when, in fact, the same strata, once continuous, have been bent round so as to recur in the same section, and with the same dip. A similar mistake has often been occasioned by a series of faults.

If, for example, the dark line A H (fig. 87.) represent the surface of a country on which the strata *a b c* frequently crop out, an observer,

Fig. 87.



Apparent alternations of strata caused by vertical faults.

who is proceeding from H to A, might at first imagine that at every step he was approaching new strata, whereas the repetition of the same beds has been caused by vertical faults, or downthrows. Thus, suppose the original mass, A, B, C, D, to have been a set of uniformly inclined strata, and that the different masses under E F, F G, and G D, sank down successively, so as to leave vacant the spaces marked in the diagram by dotted lines, and to occupy those marked by the continuous lines, then let denudation take place along the line A H, so that the protruding masses indicated by the fainter lines are swept away,—a miner, who has not discovered the faults, finding the mass *a*, which we will suppose to be a bed of coal four times repeated, might hope to find four beds, workable to an indefinite depth, but first on arriving at the fault G he is stopped suddenly in his workings, upon reaching the strata of sandstone *c*, or on arriving at the line of fault F he comes partly upon the shale *b*, and partly on the sandstone *c*, and on reaching E he is again stopped by a wall composed of the rock *d*.

The very different levels at which the separated parts of the same strata are found on the different sides of the fissure, in some faults, is truly astonishing. One of the most celebrated in England is that called the "ninety-fathom dike," in the coal-field of Newcastle. This name has been given to it, because the same beds are ninety fathoms lower on the northern than they are on the southern side. The fissure has been filled by a body of sand, which is now in the state of sandstone, and is called the dike, which is sometimes very narrow, but in other places more than twenty yards wide.* The walls of the

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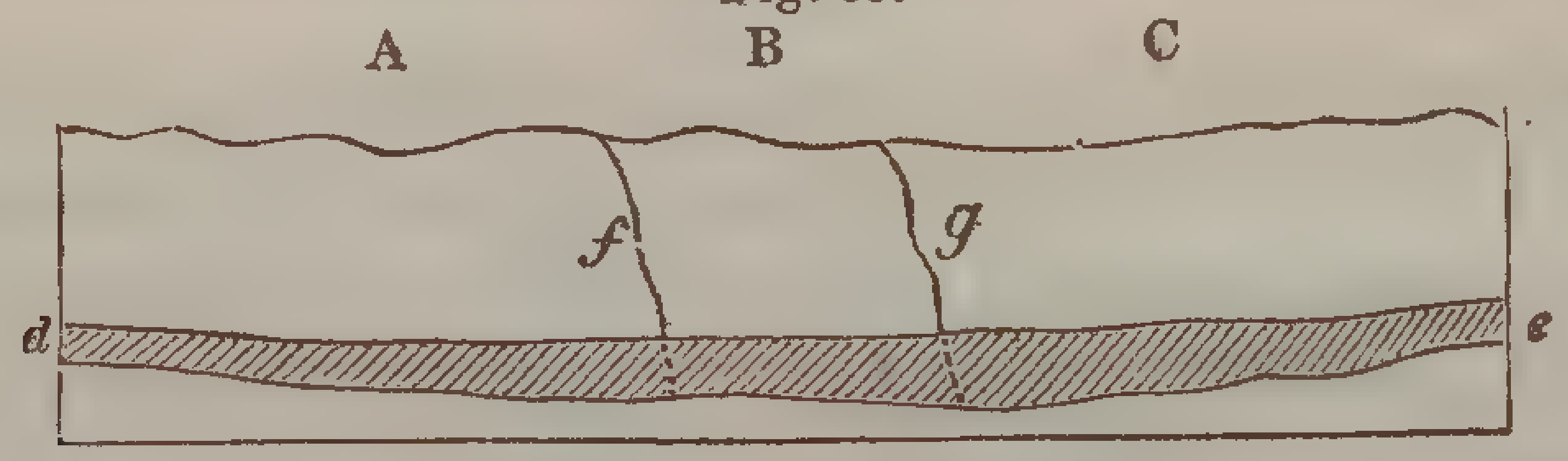
* Conybeare and Phillips, Outlines, &c. p. 376.

fissure are scored by grooves, such as would have been produced if the broken ends of the rock had been rubbed along the plane of the fault.* In the Tynedale and Craven faults, in the north of England, the vertical displacement is still greater, and the fracture has extended in a horizontal direction for a distance of thirty miles or more. Some geologists consider it necessary to imagine that the upward or downward movement in these cases was accomplished at a single stroke, and not by a series of sudden but interrupted movements. This idea appears to have been derived from a notion that the grooved walls have merely been rubbed in one direction. But this is so far from being a constant phenomenon in faults, that it has often been objected to the received theory respecting those polished surfaces called "slickensides" that the striæ are not always parallel, but often curved and irregular. It has, moreover, been remarked, that not only the walls of the fissure or fault, but its earthy contents, sometimes present the same polished and striated faces. Now these facts seem to indicate partial changes in the direction of the movement, and some slidings subsequent to the first filling up of the fissure. Suppose the mass of rock A, B, C, to overlie an extensive chasm *d e*, formed at the depth of several miles, whether by the gradual contraction in bulk of a melted mass passing into a solid or crystalline state, or the shrinking of argillaceous strata, baked by a moderate heat, or by the subtraction of matter by volcanic action, or any other cause. Now, if this region be convulsed by earthquakes, the fissures *f g*, and others at right angles to them, may sever the mass B from A and from C, so that it may move freely, and begin to sink into the chasm. A fracture may be conceived so clean and perfect as to allow it to subside at once to the bottom of the subterranean cavity; but it is far more probable that the sinking will be effected at successive periods during different earthquakes, the mass always continuing to slide in the same direction along the planes of the fissures *f g*, and the edges of the falling mass being continually more broken and triturated at each convulsion. If, as is not improbable, the circumstances which have caused the failure of support continue in operation, it may happen that when the mass B has filled the cavity first formed, its foundations will again give way under it, so that it will fall again in the same direction. But, if the direction should change, the fact could not be discovered by observing the slickensides, because the last scoring would efface the lines of previous friction. In the present state of our ignorance of the causes of subsidence, an hypothesis which can explain the great amount of displacement in some faults, on sound mechanical principles, by a

Fig. 88.



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* Phillips, Geology, Lardner's Cyclop. p. 41.

succession of movements, is far preferable to any theory which assumes each fault to have been accomplished by a single upcast or downthrow of several thousand feet. For we know that there are operations now in progress, at great depths in the interior of the earth, by which both large and small tracts of ground are made to rise above and sink below their former level, some slowly and insensibly, others suddenly and by starts, a few feet or yards at a time; whereas there are no grounds for believing that, during the last 3000 years at least, any regions have been either upheaved or depressed, at a single stroke, to the amount of several hundred, much less several thousand feet. When some of the ancient marine formations are described in the sequel, it will appear that their structure and organic contents point to the conclusion, that the floor of the ocean was slowly sinking at the time of their origin. The downward movement was very gradual, and in Wales and the contiguous parts of England a maximum thickness of 32,000 feet (more than six miles) of Carboniferous, Devonian, and Silurian rock was formed, whilst the bed of the sea was all the time continuously and tranquilly subsiding.* Whatever may have been the changes which the solid foundation underwent, whether accompanied by the melting, consolidation, crystallization, or desiccation of subjacent mineral matter, it is clear from the fact of the sea having remained shallow all the while that the bottom never sank down suddenly to the depth of many hundred feet at once.

It is by assuming such reiterated variations of level, each separately of small vertical amount, but multiplied by time till they acquire importance in the aggregate, that we are able to explain the phenomena of denudation, which will be treated of in the next chapter. By such movements, every portion of the surface of the land becomes in its turn a line of coast, and is exposed to the action of the waves and tides. A country which is undergoing such movement is never allowed to settle into a state of equilibrium, therefore the force of rivers and torrents to remove or excavate soil and rocky masses is sustained in undiminished energy.

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* See the results of the "Geological Survey of Great Britain;" Memoirs, vols. i. and ii., by Sir H. De la Beche, Mr. A. C. Ramsay, and Mr. John Phillips.

CHAPTER VI.

DENUDATION.

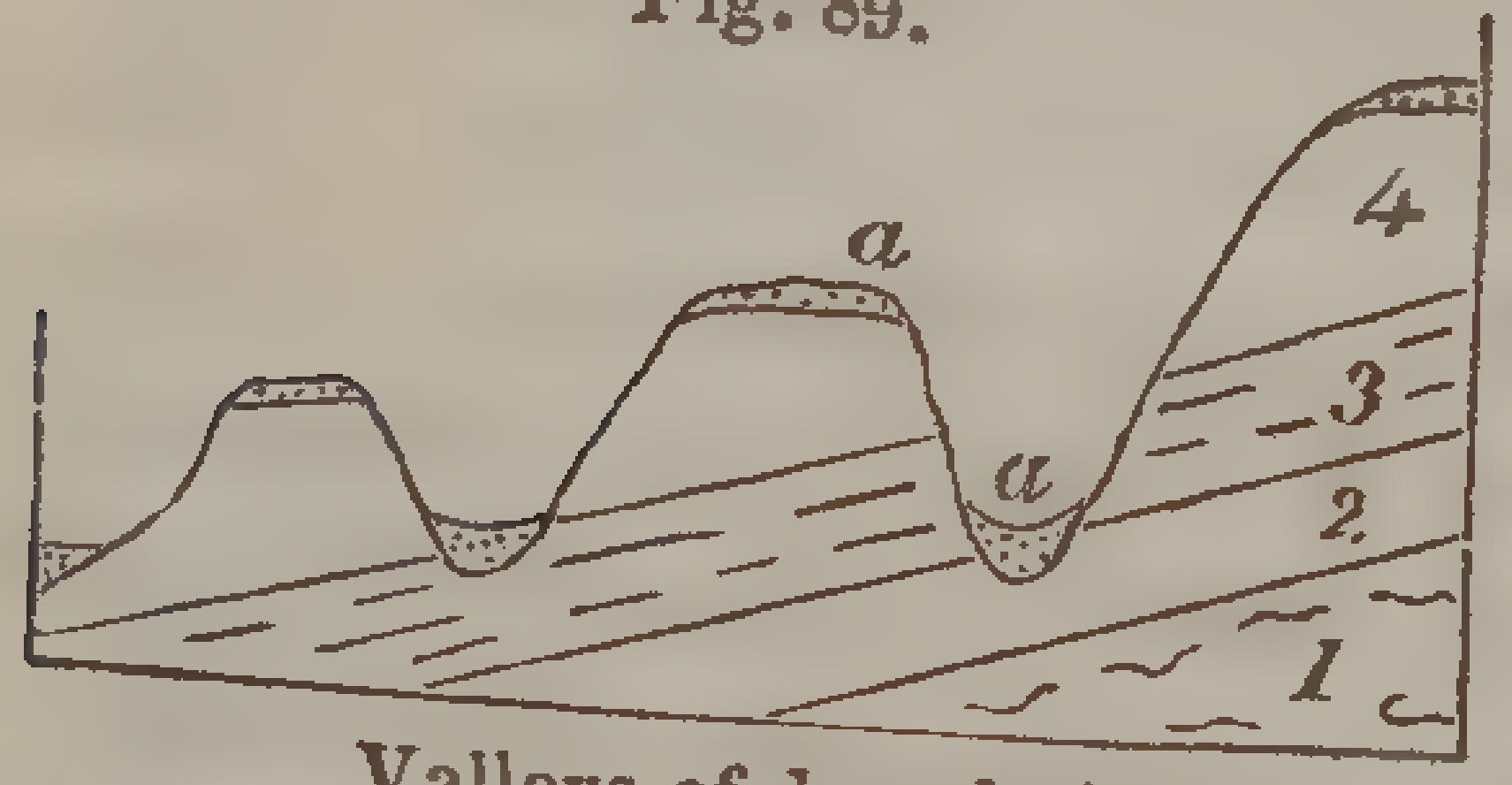
Denudation defined — Its amount equal to the entire mass of stratified deposits in the earth's crust — Horizontal sandstone denuded in Ross-shire — Levelled surface of countries in which great faults occur — Coalbrook Dale — Denuding power of the ocean during the emergence of land — Origin of Valleys — Obliteration of sea-cliffs — Inland sea-cliffs and terraces in the Morea and Sicily — Limestone pillars at St. Mihiel, in France — in Canada — in the Bermudas.

DENUDATION, which has been occasionally spoken of in the preceding chapters, is the removal of solid matter by water in motion, whether of rivers or of the waves and currents of the sea, and the consequent laying bare of some inferior rock. Geologists have perhaps been seldom in the habit of reflecting that this operation has exerted an influence on the structure of the earth's crust as universal and important as sedimentary deposition itself; for denudation is the inseparable accompaniment of the production of all new strata of mechanical origin. The formation of every new deposit by the transport of sediment and pebbles necessarily implies that there has been, somewhere else, a grinding down of rock into rounded fragments, sand, or mud, equal in quantity to the new strata. All deposition, therefore, except in the case of a shower of volcanic ashes, is the sign of superficial waste going on contemporaneously, and to an equal amount elsewhere. The gain at one point is no more than sufficient to balance the loss at some other. Here a lake has grown shallower, there a ravine has been deepened. The bed of the sea has in one region been raised by the accumulation of new matter, in another its depth has been augmented by the abstraction of an equal quantity.

When we see a stone building, we know that somewhere, far or near, a quarry has been opened. The courses of stone in the building may be compared to successive strata, the quarry to a ravine or valley which has suffered denudation. As the strata, like the courses of hewn stone, have been laid one upon another gradually, so the excavation both of the valley and quarry have been gradual. To pursue the comparison still farther, the superficial heaps of mud, sand, and gravel, usually called alluvium, may be likened to the rubbish of a quarry which has been rejected as useless by the workmen, or has fallen upon the road between the quarry and the building, so as to lie scattered at random over the ground.

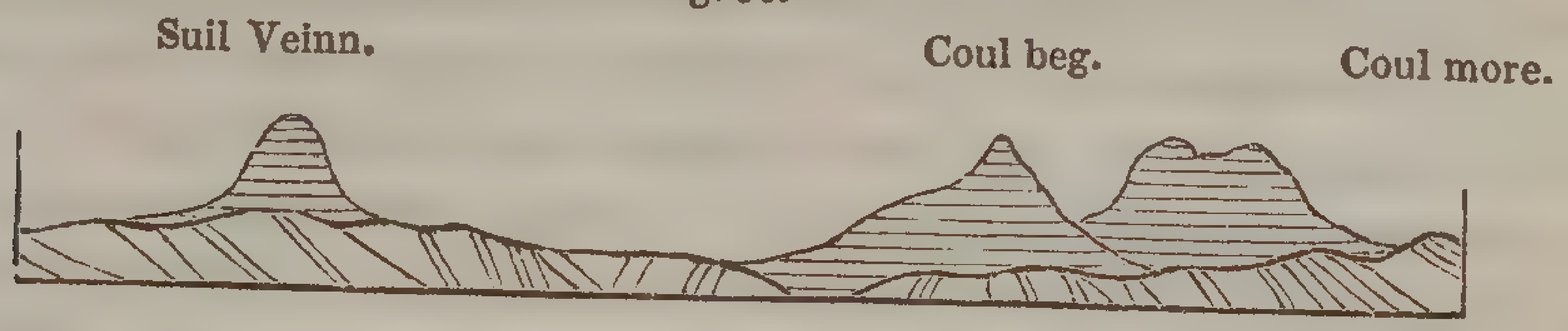
If, then, the entire mass of stratified deposits in the earth's crust is at once the monument and measure of the denudation which has taken place, on how stupendous a scale ought we to find the signs of this removal of transported materials in past ages! Accordingly, there are different classes of phenomena, which attest in a most striking manner the vast spaces left vacant by the erosive power of water. I may allude, first, to those valleys on both sides of which the same strata are seen following each other in the same order, and having the same mineral composition and fossil contents. We may observe, for example, several formations, as Nos. 1, 2, 3, 4, in the accompanying diagram (fig. 89.); No. 1. conglomerate, No. 2. clay, No. 3. grit, and No. 4. limestone, each repeated in a series of hills separated by valleys varying in depth. When we examine the subordinate parts of these four formations, we find, in like manner, distinct beds in each, corresponding, on the opposite sides of the valleys, both in composition and order of position. No one can doubt that the strata were originally continuous, and that some cause has swept away the portions which once connected the whole series. A torrent on the side of a mountain produces similar interruptions; and when we make artificial cuts in lowering roads, we expose, in like manner, corresponding beds on either side. But in nature, these appearances occur in mountains several thousand feet high, and separated by intervals of many miles or leagues in extent, of which a grand exemplification is described by Dr. Macculloch, on the north-western coast of Ross-shire in Scotland.*

Fig. 89.



Valleys of denudation.
a. alluvium.

Fig. 90.



Denudation of red sandstone on north-west coast of Ross-shire. (Macculloch.)

The fundamental rock of that country is gneiss, in disturbed strata, on which beds of nearly horizontal red sandstone rest unconformably. The latter are often very thin, forming mere flags, with their surfaces, distinctly ripple-marked. They end abruptly on the declivities of many insulated mountains, which rise up at once to the height of about 2000 feet above the gneiss of the surrounding plain or table land, and to an average elevation of about 3000 feet above the sea, which all their summits generally attain. The base of gneiss varies in height, so that the lower portions of the sandstone occupy different levels, and the thickness of the mass is various, sometimes exceeding 3000 feet. It is impossible to compare these scattered and detached portions without imagining that the whole country has once been covered with a great body of sandstone, and that masses from 1000 to more than 3000 feet in thickness have been removed.

In the "Survey of Great Britain" (vol. i.), Professor Ramsay has shown that the missing beds, removed from the summit of the Mendips, must have been nearly a mile in thickness; and he has pointed out considerable areas in South Wales and some of the ad-

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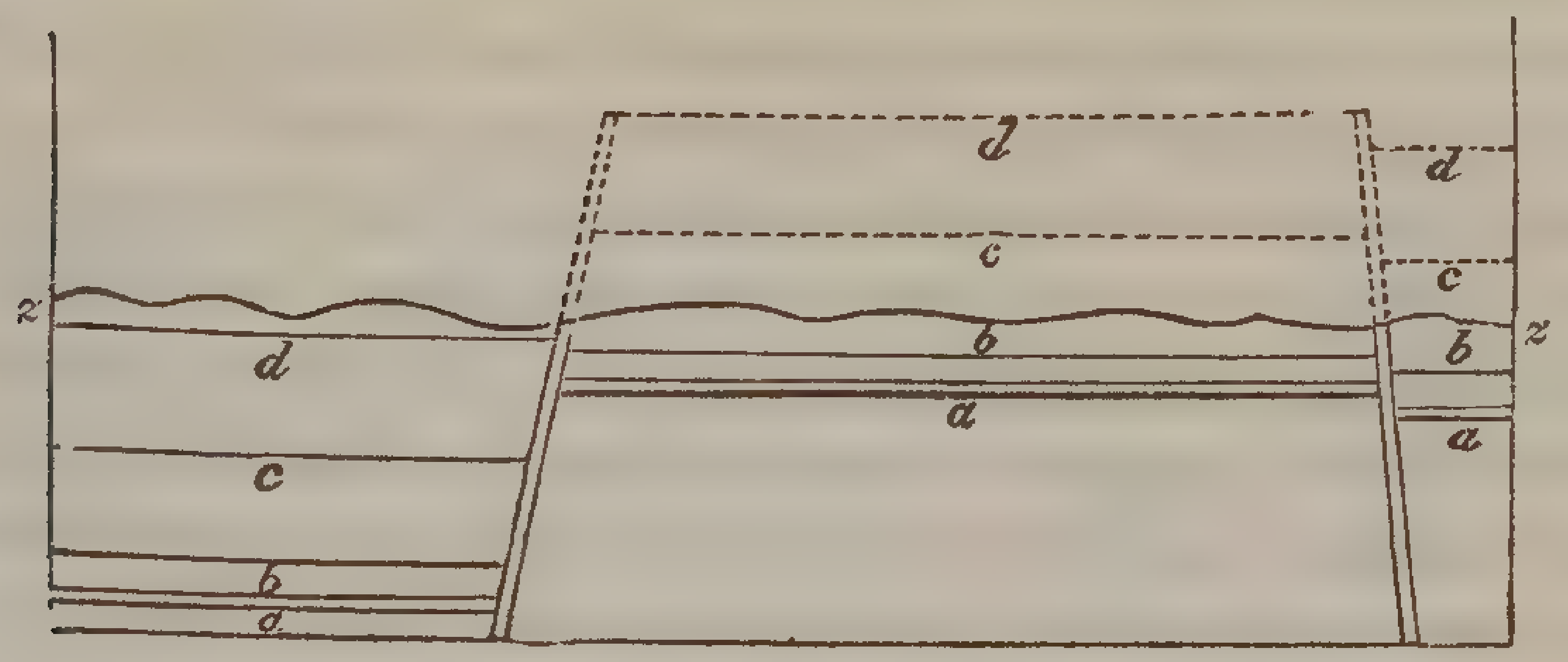
* Western Islands, vol. ii. p. 93. pl. 31. fig. 4.

jacent counties of England, where a series of primary (or palæozoic) strata, not less than 11,000 feet in thickness, have been stripped off. All these materials have of course been transported to new regions, and have entered into the composition of more modern formations. On the other hand, it is shown by observations in the same "Survey," that the palæozoic strata are from 20,000 to 30,000 feet thick. It is clear that such rocks, formed of mud and sand, now for the most part consolidated, are the monuments of denuding operations, which took place on a grand scale at a very remote period in the earth's history. For, whatever has been given to one area must always have been borrowed from another; a truth which, obvious as it may seem when thus stated, must be repeatedly impressed on the student's mind, because in many geological speculations it is taken for granted that the external crust of the earth has been always growing thicker in consequence of the accumulation, period after period, of sedimentary matter, as if the new strata were not always produced at the expense of pre-existing rocks, stratified or unstratified. By duly reflecting on the fact, that all deposits of mechanical origin imply the transportation from some other region, whether contiguous or remote, of an equal amount of solid matter, we perceive that the stony exterior of the planet must always have grown thinner in one place, whenever, by accessions of new strata, it was acquiring density in another. No doubt the vacant space left by the missing rocks, after extensive denudation, is less imposing to the imagination than a vast thickness of conglomerate or sandstone, or the bodily presence as it were of a mountain-chain, with all its inclined and curved strata. But the denuded tracts speak a clear and emphatic language to our reason, and, like repeated layers of fossil nummulites, corals or shells, or like numerous seams of coal, each based on its under-clay full of the roots of trees, still remaining in their natural position, demand an indefinite lapse of time for their elaboration.

No one will maintain that the fossils entombed in these rocks did not belong to many successive generations of plants and animals. In like manner, each sedimentary deposit attests a slow and gradual action, and the strata not only serve as a measure of the amount of denudation simultaneously effected elsewhere, but are also a correct indication of the rate at which the denuding operation was carried on.

Perhaps the most convincing evidence of denudation on a magnificent scale is derived from the levelled surfaces of districts where large faults occur. I have shown, in fig. 87. p. 63., and in fig. 91., how angular and protruding masses of rock might naturally have been looked for on the surface immediately above great faults, although in fact they rarely exist. This phenomenon may be well studied in those districts where coal has been extensively worked, for there the former relation of the beds which have shifted their position may be determined with great accuracy. Thus in the coal field of Ashby de la Zouch, in Leicestershire (see fig. 91.), a fault occurs, on one side of which the coal beds *a b c d* rise to the height of 500 feet

Fig. 91.



Faults and denuded coal strata, Ashby de la Zouch. (Mammatt.)

above the corresponding beds on the other side. But the uplifted strata do not stand up 500 feet above the general surface; on the contrary, the outline of the country, as expressed by the line *z z*, is uniformly undulating without any break, and the mass indicated by the dotted outline must have been washed away.* There are proofs of this kind in some level countries, where dense masses of strata have been cleared away from areas several hundred square miles in extent.

In the Newcastle coal district it is ascertained that faults occur in which the upward or downward movement could not have been less than 140 fathoms, which, had they affected the configuration of the surface to an equal amount, would produce mountains with precipitous escarpments nearly 1000 feet high, or chasms of the like depth; yet is the actual level of the country absolutely uniform, affording no trace whatever of subterranean movements.†

The ground from which these materials have been removed is usually overspread with heaps of sand and gravel, formed out of the ruins of the very rocks which have disappeared. Thus, in the districts above referred to, they consist of rounded and angular fragments of hard sandstone, limestone, and ironstone, with a small quantity of the more destructible shale, and even rounded pieces of coal.

Allusion has been already made to the shattered state and discordant position of the carboniferous strata in Coalbrook Dale (p. 62.). The collier cannot proceed three or four yards without meeting with small slips, and from time to time he encounters faults of considerable magnitude, which have thrown the rocks up or down several hundred feet. Yet the superficial inequalities to which these dislocated masses originally gave rise are no longer discernible, and the comparative flatness of the existing surface can only be explained, as Mr. Prestwich has observed, by supposing the fractured portions to have been removed by water. It is also clear that strata of red sandstone, more than 1000 feet thick, which once covered the coal, in the same region, have been carried away from large areas. That water has, in this case, been the denuding agent, we may infer from the fact that the rocks have yielded according to

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* See Mammat's Geological Facts, &c. p. 90. and plate.

† Conybeare's Report to Brit. Assoc. 1842, p. 381.

their different degrees of hardness; the hard trap of the Wrekin, for example, and other hills, having resisted more than the softer shale and sandstone, so as now to stand out in bold relief.*

Origin of valleys.—Many of the earlier geologists, and Dr. Hutton among them, taught that "rivers have in general hollowed out their valleys." This is no doubt true of rivulets and torrents which are the feeders of the larger streams, and which, descending over rapid slopes, are most subject to temporary increase and diminution in the volume of their waters. It must also be admitted that the quantity of mud, sand, and pebbles constituting many a modern delta is so considerable as to prove that a very large part of the inequalities now existing on the earth's surface are due to fluviatile action; but the principal valleys in almost every great hydrographical basin in the world, are of a shape and magnitude which imply that they have been due to other causes besides the mere excavating power of rivers.

Some geologists have imagined that a deluge, or succession of deluges, may have been the chief denuding agency, and they have speculated on a series of enormous waves raised by the instantaneous upthrow of continents or mountain chains out of the sea. But even were we disposed to grant such sudden upheavals of the floor of the ocean, and to assume that great waves would be the consequence of each convulsion, it is not easy to explain the observed phenomena by the aid of so gratuitous an hypothesis.

On the other hand, a machinery of a totally different kind seems capable of giving rise to effects of the required magnitude. It has now been ascertained that the rising and sinking of extensive portions of the earth's crust, whether insensibly or by a repetition of sudden shocks, is part of the actual course of nature, and we may easily comprehend how the land may have been exposed during these movements to abrasion by the waves of the sea. In the same manner as a mountain mass may, in the course of ages, be formed by sedimentary deposition, layer after layer, so masses equally voluminous may in time waste away by inches; as, for example, if beds of incoherent materials are raised slowly in an open sea where a strong current prevails. It is well known that some of these oceanic currents have a breadth of 200 miles, and that they sometimes run for a thousand miles or more in one direction, retaining a considerable velocity even at the depth of several hundred feet. Under these circumstances, the flowing waters may have power to clear away each stratum of incoherent materials as it rises and approaches the surface, where the waves exert the greatest force; and in this manner a voluminous deposit may be entirely swept away, so that, in the absence of faults, no evidence may remain of the denuding operation. It may indeed be affirmed that the signs of waste will usually be least obvious where the destruction has been most complete; for the annihilation may have proceeded so far, that no ruins are left of the dilapidated rocks.

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* Prestwich, Geol. Trans. second series, vol. v. pp. 452. 473.

Although denudation has had a levelling influence on some countries of shattered and disturbed strata (see fig. 87. p. 63. and fig. 91. p. 69.), it has more commonly been the cause of superficial inequalities, especially in regions of horizontal stratification. The general outline of these regions is that of flat and level platforms, interrupted by valleys often of considerable depth, and ramifying in various directions. These hollows may once have formed bays and channels between islands, and the steepest slope on the sides of each valley may have been a sea-cliff, which was undermined for ages, as the land emerged gradually from the deep. We may suppose the position and course of each valley to have been originally determined by differences in the hardness of the rocks, and by rents and joints which usually occur even in horizontal strata. In mountain chains, such as the Jura before described (see fig. 71. p. 55.), we perceive at once that the principal valleys have not been due to aqueous excavation, but to those mechanical movements which have bent the rocks into their present form. Yet even in the Jura there are many valleys, such as C (fig. 71.), which have been hollowed out by water; and it may be stated that in every part of the globe the unevenness of the surface of the land has been due to the combined influence of subterranean movements and denudation.

I may now recapitulate a few of the conclusions to which we have arrived: first, all the mechanical strata have been accumulated gradually, and the concomitant denudation has been no less gradual: secondly, the dry land consists in great part of strata formed originally at the bottom of the sea, and has been made to emerge and attain its present height by a force acting from beneath: thirdly, no combination of causes has yet been conceived so capable of producing extensive and gradual denudation, as the action of the waves and currents of the ocean upon land slowly rising out of the deep.

Now, if we adopt these conclusions, we shall naturally be led to look everywhere for marks of the former residence of the sea upon the land, especially near the coasts from which the last retreat of the waters took place, and it will be found that such signs are not wanting.

I shall have occasion to speak of ancient sea-cliffs, now far inland, in the south-east of England, when treating in Chapter XIX. of the denudation of the chalk in Surrey, Kent, and Sussex. Lines of upraised sea-beaches of more modern date are traced, at various levels from 20 to 100 feet and upwards above the present sea-level, for great distances on the east and west coasts of Scotland, as well as in Devonshire, and other counties in England. These ancient beach-lines often form terraces of sand and gravel, including littoral shells, some broken, others entire, and corresponding with species now living on the adjoining coast. But it would be unreasonable to expect to meet everywhere with the signs of ancient shores, since no geologist can have failed to observe how soon all recent marks of the kind above alluded to are obscured or entirely effaced, wherever, in consequence of the altered state of the tides and currents, the sea has receded for a few centuries. We see the cliffs crumble down in a few years if composed of sand or clay, and soon reduced to a gentle slope. If there were shells on the beach, they decompose, and their materials are washed away, after which the sand and shingle may resemble any other alluviums scattered over the interior.

The features of an ancient shore may sometimes be concealed by the growth of trees and shrubs, or by a covering of blown sand, a good example of which occurs a few miles west from Dax, near Bourdeaux, in the south of France. About twelve miles inland, a steep bank may be traced running in a direction nearly north-east and south-west, or parallel to the contiguous coast. This sudden fall of about 50 feet conducts us from the higher platform of the Landes to a lower plain which extends to the sea. The outline of the ground suggested to me, as it would do to every geologist, the opinion that the bank in question was once a sea-cliff, when the whole country stood at a lower level. But this is no longer matter of conjecture, for, in making excavations in 1830 for the foundation of a building at Abesse, a quantity of loose sand, which formed the slope *d e*, was removed; and a perpendicular cliff, about 50 feet in height, which had hitherto been protected from the agency of the elements, was exposed. At the bottom appeared the limestone *b*, containing tertiary shells and corals, immediately below it the clay *c*, and above it the usual tertiary sand *a*, of the department of the Landes. At the base of the precipice were seen large partially rounded masses of rock, evidently detached from the stratum *b*. The face of the limestone was hollowed out and weathered into such forms as are seen in the calcareous cliffs of the adjoining coast, especially at Biaritz, near Bayonne. It is evident that, when this country stood at a somewhat lower level, the sea advanced along the surface of the argillaceous stratum *c*, which, from its yielding nature, favoured the waste by allowing the more solid superincumbent stone *b* to be readily undermined. Afterwards, when the country had been elevated, part of the sand, *a*, fell down, or was drifted by the winds, so as to form the talus, *d e*, which masked the inland cliff until it was artificially laid open to view.

Fig. 92.

Section of inland cliff at Abesse, near Dax.
a. Sand of the Landes. *b.* Limestone. *c.* Clay.

When we are considering the various causes which, in the course of ages, may efface the characters of an ancient sea-coast, earthquakes must not be forgotten. During violent shocks, steep and overhanging cliffs are often thrown down and become a heap of ruins. Sometimes unequal movements of upheaval or depression entirely destroy that horizontality of the base-line which constitutes the chief peculiarity of an ancient sea-cliff.

It is, however, in countries where hard limestone rocks abound, that inland cliffs retain faithfully the characters which they acquired when they constituted the boundary of land and sea. Thus, in the Morea, no less than three, or even four, ranges of what were once sea-cliffs are well preserved. These have been described, by MM. Boblaye and Virlet, as rising one above the other at different distances from the actual shore, the summit of the highest and oldest occasionally exceeding 1000 feet in elevation. At the base of each there is usually a terrace, which is in some places a few yards, in others above 300 yards wide, so that we are conducted from the high land of the interior to the sea by a succession of great steps. These inland cliffs are most perfect, and most exactly resemble those now washed by the waves of the Mediterranean, where they are formed of calcareous rock, especially if the rock be a hard crystalline marble. The following are the points of correspondence observed between the ancient coast lines and the borders of the present sea:—1. A range of vertical precipices, with a terrace at their base. 2. A weathered state of the surface of the naked rock, such as the spray of the sea produces. 3. A line of littoral caverns at the foot of the cliffs. 4. A consolidated beach or breccia with occasional marine shells, found at the base of the cliffs, or in the caves. 5. Lithodomous perforations.

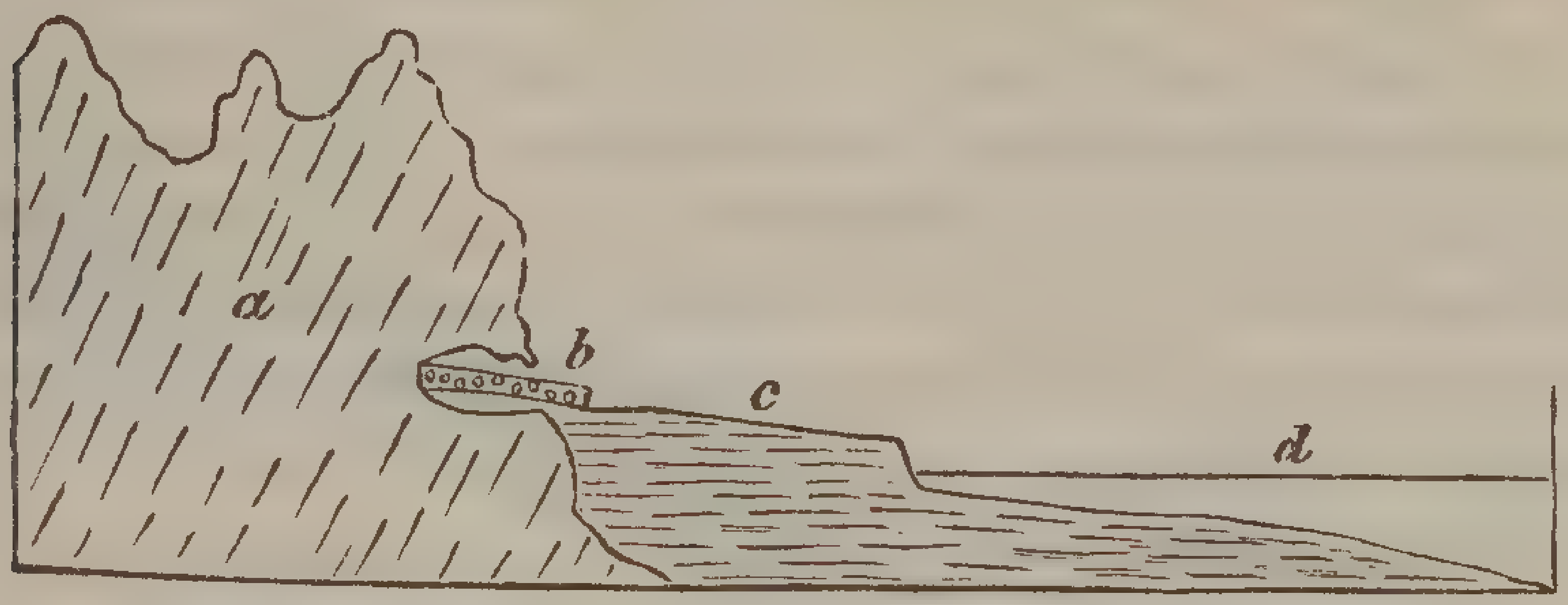
In regard to the first of these, it would be superfluous to dwell on the evidence afforded of the undermining power of waves and currents by perpendicular precipices. The littoral caves, also, will be familiar to those who have had opportunities of observing the manner in which the waves of the sea, when they beat against rocks, have power to scoop out caverns. As to the breccia, it is composed of pieces of limestone and rolled fragments of thick solid shell, such as *Strombus* and *Spondylus*, all bound together by a crystalline calcareous cement. Similar aggregations are now forming on the modern beaches of Greece, and in caverns on the sea-side; and they are only distinguishable in character from those of more ancient date, by including many pieces of pottery. In regard to the *lithodomi* above alluded to, these bivalve mollusks are well known to have the power of excavating holes in the hardest limestones, the size of the cavity keeping pace with the growth of the shell. When living they require to be always covered by salt water, but similar pear-shaped hollows, containing the dead shells of these creatures, are found at different heights on the face of the inland cliffs above mentioned. Thus, for example, they have been observed near Modon and Navarino on cliffs in the interior 125 feet high above the Mediterranean. As to the weathered surface of the calcareous rocks, all limestones are known to suffer chemical decomposition when moistened by the spray of the salt water, and are corroded still more deeply at points lower down where they are just reached by the breakers. By this action the stone acquires a wrinkled and furrowed outline, and very near the sea it becomes rough and branching, as if covered with corals. Such effects are traced not only on the present shore, but at the base of the ancient cliffs far in the interior. Lastly, it remains only to speak of the terraces, which extend with a gentle slope from the base of almost all the inland cliffs, and are for the most part narrow where the rock is hard, but sometimes half a mile or more in breadth where it is soft. They are the effects of the encroachment of the ancient sea upon the shore at those levels at which the land remained for a long time stationary. The justness of this view is apparent on examining the shape of the modern shore wherever the sea is advancing upon the land, and removing annually small portions of undermined rock. By this agency a submarine platform is produced on which we may walk for some distance from the beach in shallow water, the increase of depth being very gradual, until we reach a point where the bottom plunges down suddenly. This platform is widened with more or less rapidity according to the hardness of the rocks, and when upraised it constitutes an inland terrace.

But the four principal lines of cliff observed in the Morea do not imply, as some have imagined, four great eras of sudden upheaval; they simply indicate the intermittence of the upheaving force. Had the rise of the land been continuous and uninterrupted, there would have been no one prominent line of cliff; for every portion of the surface having been, in its turn, and for an equal period of time, a sea-shore, would have presented a nearly similar aspect. But if pauses occur in the process of upheaval, the waves and currents have time to sap, throw down, and clear away considerable masses of rock, and to shape out at several successive levels lofty ranges of cliffs with broad terraces at their base.

There are some levelled spaces, however, both ancient and modern, in the Morea, which are not due to denudation, although resembling in outline the terraces above described. They may be called Terraces of Deposition, since they have resulted from the gain of land upon the sea where rivers and torrents have produced deltas. If the sedimentary matter has filled up a bay or gulf surrounded by steep mountains, a flat plain is formed skirting the inland precipices; and if these deposits are upraised, they form a feature in the landscape very similar to the areas of denudation before described.

In the island of Sicily I have examined many inland cliffs like those of the Morea; as, for example, near Palermo, where a precipice is seen consisting of limestone at the base of which are numerous caves. One of these, called San Ciro, about 2 miles distant from Palermo, is about 20 feet high, 10 wide, and 180 above the sea. Within it is found an ancient beach (*b*, fig. 93.), formed of pebbles of various rocks, many of which must have come from places far remote. Broken pieces of coral and shell, especially of oysters and pectens, are seen intermingled with the pebbles. Immediately above the level of this beach, *serpulæ* are still found adhering to the face of the rock, and the limestone is perforated by *lithodomi*. Within the grotto, also, at the same level, similar perforations occur; and so numerous are the holes, that the rock is compared by Hoffmann to a target pierced by musket balls. But in order to expose to view these

Fig. 93.



a. Monte Grifone. *b.* Cave of San Ciro.* *c.* Plain of Palermo, in which are Newer Pliocene strata of limestone and sand. *d.* Bay of Palermo.

marks of boring-shells in the interior of the cave, it was necessary first to remove a mass of breccia, which consisted of numerous fragments of rock and an immense quantity of bones of the mammoth, hippopotamus, and other quadrupeds, imbedded in a dark brown calcareous marl. Many of the bones were rolled as if partially subjected to the action of the waves. Below this breccia, which is about 20 feet thick, was found a bed of sand filled with sea-shells of recent species; and underneath the sand, again, is the secondary limestone of Monte Grifone. The state of the surface of the limestone in the cave above the level of the marine sand is very different from that below it. *Above*, the rock is jagged and uneven, as is usual in the roofs and sides of limestone caverns; *below*, the surface is smooth and polished, as if by the attrition of the waves.

The platform indicated at *c*, fig. 93., is formed by a tertiary deposit containing marine shells almost all of living species, and it affords an illustration of the terrace of deposition, or the last of the two kinds before mentioned (p. 74.).

There are also numerous instances in Sicily of terraces of denudation. One of these occurs on the east coast to the north of Syracuse, and the same is resumed to the south beyond the town of Noto, where it may be traced forming a continuous and lofty precipice, *a b*, fig. 94., facing towards the sea, and constituting the abrupt termination of a calcareous formation, which extends in horizontal strata far inland. This precipice varies in height from 500 to 700 feet, and between its base and the sea is an inferior platform, *c b*, consisting of similar white limestone. All the beds dip towards the sea, but are usually inclined at a very slight angle: they are seen to extend uninterruptedly from the base of the escarpment into the platform, showing distinctly that the lofty cliff was not produced by a fault or vertical shift of the beds, but by the removal of a considerable mass of rock. Hence we may conclude that the sea, which is now undermining the cliffs of the Sicilian coast, reached at some former period the base of the precipice *a b*, at which time the surface of the terrace *c b* must have

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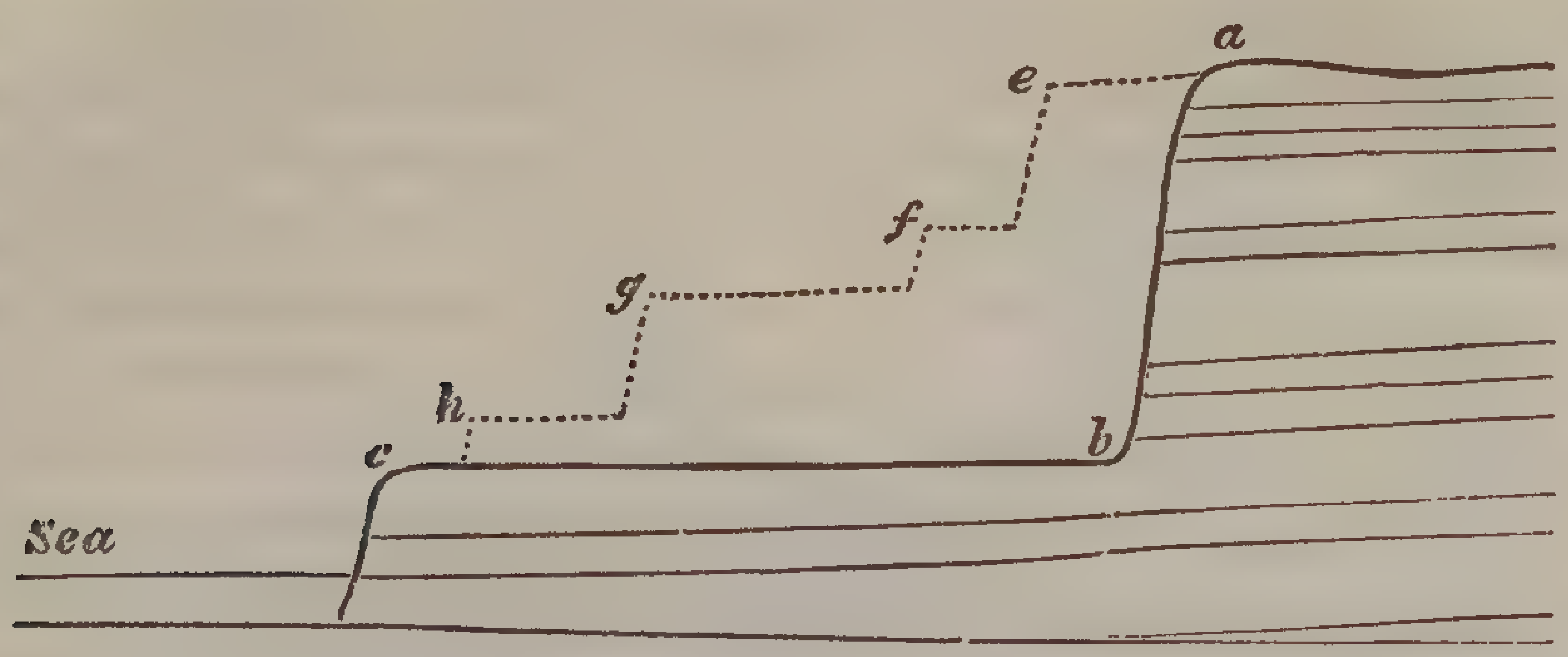
* Section given by Dr. Christie, Edin. New Phil. Journ. No. xxiii., called by mistake the Cave of Mardolce, by the late M. Hoffmann. See account by Mr. S. P. Pratt, F. G. S., Proceedings of Geol. Soc. No. 32. 1833.

Fig. 94.



been covered by the Mediterranean. There was a pause, therefore, in the upward movement, when the waves of the sea had time to carve out the platform *c b;* but there may have been many other stationary periods of minor duration. Suppose, for example, that a series of escarpments *e*, *f*, *g*, *h*, once existed, and that the sea, during a long interval free from subterranean movements, advances along the line *c b*, all preceding cliffs must have been swept away one after the other, and reduced to the single precipice *a b*.

That such a series of smaller cliffs, as those represented at *e*, *f*, *g*, *h*, fig. 94., did really once exist at intermediate heights in place of the single precipice *a b*, is rendered highly probable by the fact, that in certain bays and inland valleys opening towards the east coast of Sicily, and not far from the section given in fig. 94., the solid limestone is shaped out into a great succession of ledges, separated from each other by small vertical cliffs. These are sometimes so numerous, one above the other, that where there is a bend at the head of a valley, they produce an effect singularly resembling the seats of a Roman amphitheatre. A good example of this configuration occurs near the town of Melilli, as seen in the annexed view (fig. 95.). In the south of the island, near Spaccaforno Scicli, and Modica, preci-

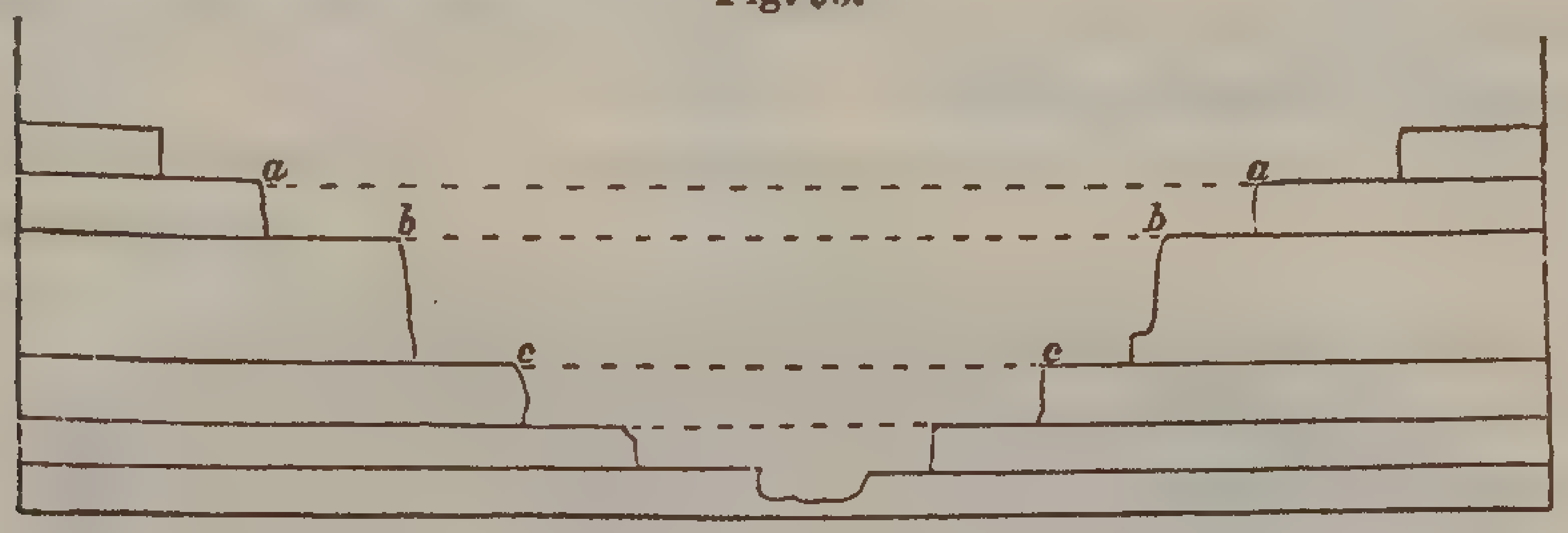
Fig. 95.

Valley called Gozzo degli Martiri, below Melilli, Val di Noto.

pitous rocks of white limestone, ascending to the height of 500 feet, have been carved out into similar forms.

This appearance of a range of marble seats circling round the head of a valley, or of great flights of steps descending from the top to the bottom, on the opposite sides of a gorge, may be accounted for, as already hinted, by supposing the sea to have stood successively at many different levels, as at *a a*, *b b*, *c c*, in the accompanying fig. 96. But the causes of the gradual contraction of the valley from above downwards may still be matter of speculation. Such contraction may be due to the greater force exerted by the waves when the land at its first emergence was smaller in quantity, and more exposed to denudation in an open sea; whereas the wear and tear of the rocks might diminish in proportion as this action became confined within bays or channels closed in on two or three sides. Or, secondly, the separate movements of elevation may have followed each other more rapidly as the land continued to rise, so that the times of those pauses, during which the greatest denudation was accomplished at certain levels, were always growing shorter. It should be remarked, that the cliffs and small terraces are rarely found on the opposite sides of the Sicilian valleys at heights so precisely answering to each other as those given in fig. 96., and this might have been expected, to whichever of the two hypotheses above explained we incline; for, according to the direction of the prevailing winds and currents, the waves may beat with unequal force on different parts of the shore, so that while no impression is made on one side of a bay, the sea may encroach so far on the other as to unite several smaller cliffs into one.

Fig. 96.



Before quitting the subject of ancient sea-cliffs, carved out of limestone, I shall mention the range of precipitous rocks, composed of a white marble of the Oolitic period, which I have seen near the northern gate of St. Mihiel in France. They are situated on the right bank of the Meuse, at a distance of 200 miles from the nearest sea, and they present on the precipice facing the river three or four horizontal grooves, one above the other, precisely resembling those which are scooped out by the undermining waves. The summits of several of these masses are detached from the adjoining hill, in which case the grooves pass all round them, facing towards all points of the compass, as if they had once formed rocky islets near the shore.*

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* I was directed by M. Deshayes to this spot, which I visited in June, 1833.

Captain Bayfield, in his survey of the Gulf of St. Lawrence, discovered in several places, especially in the Mingan islands, a counterpart of the inland cliffs of St. Mihiel, and traced a succession of shingle beaches, one above the other, which agreed in their level with some of the principal grooves scooped out of the limestone pillars. These beaches consisted of calcareous shingle, with shells of recent species, the farthest from the shore being 60 feet above the level of the highest tides. In addition to the drawings of the pillars called the flower-pots, which he has published *, I have been favoured with other views of rocks on the same coast, drawn by Lieut. A. Bowen, R.N. (See fig. 97.)

Fig. 97.

Limestone columns in Niapisca Island, in the Gulf of St. Lawrence. Height of the second column on the left, 60 feet.

In the North-American beaches above mentioned rounded fragments of limestone have been found perforated by *lithodomi;* and holes drilled by the same mollusks have been detected in the columnar rocks or "flower-pots," showing that there has been no great amount of atmospheric decomposition on the surface, or the cavities alluded to would have disappeared.

We have an opportunity of seeing in the Bermuda islands the manner in which the waves of the Atlantic have worn, and are now wearing out, deep smooth hollows on every side of projecting masses of hard limestone. In the annexed drawing, communicated to me

Fig. 98.

The North Rocks, Bermuda, lying outside the great coral reef.
A. 16 feet high, and B. 12 feet. *c. c.* Hollows worn by the sea.

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* See Trans. of Geol. Soc., second series, vol. v. plate v.

by Capt. Nelson, R.E., the excavations *c*, *c*, *c*, have been scooped out by the waves in a stone of very modern date, which, although extremely hard, is full of recent corals and shells, some of which retain their colour.

When the forms of these horizontal grooves, of which the surface is sometimes smooth and almost polished, and the roofs of which often overhang to the extent of 5 feet or more, have been carefully studied by geologists, they will serve to testify the former action of the waves at innumerable points far in the interior of the continents. But we must learn to distinguish the indentations due to the original action of the sea, and those caused by subsequent chemical decomposition of calcareous rocks, to which they are liable in the atmosphere.

I shall conclude with a warning to beginners not to feel surprise if they can detect no evidence of the former sojourn of the sea on lands which we are nevertheless sure have been submerged at periods comparatively modern; for notwithstanding the enduring nature of the marks left by littoral action on calcareous rocks, we can by no means detect sea-beaches and inland cliffs everywhere, even in Sicily and the Morea. On the contrary, they are, upon the whole, extremely partial, and are often entirely wanting in districts composed of argillaceous and sandy formations, which must, nevertheless, have been upheaved at the same time, and by the same intermittent movements, as the adjoining calcareous rocks.

CHAPTER VII.

ALLUVIUM.

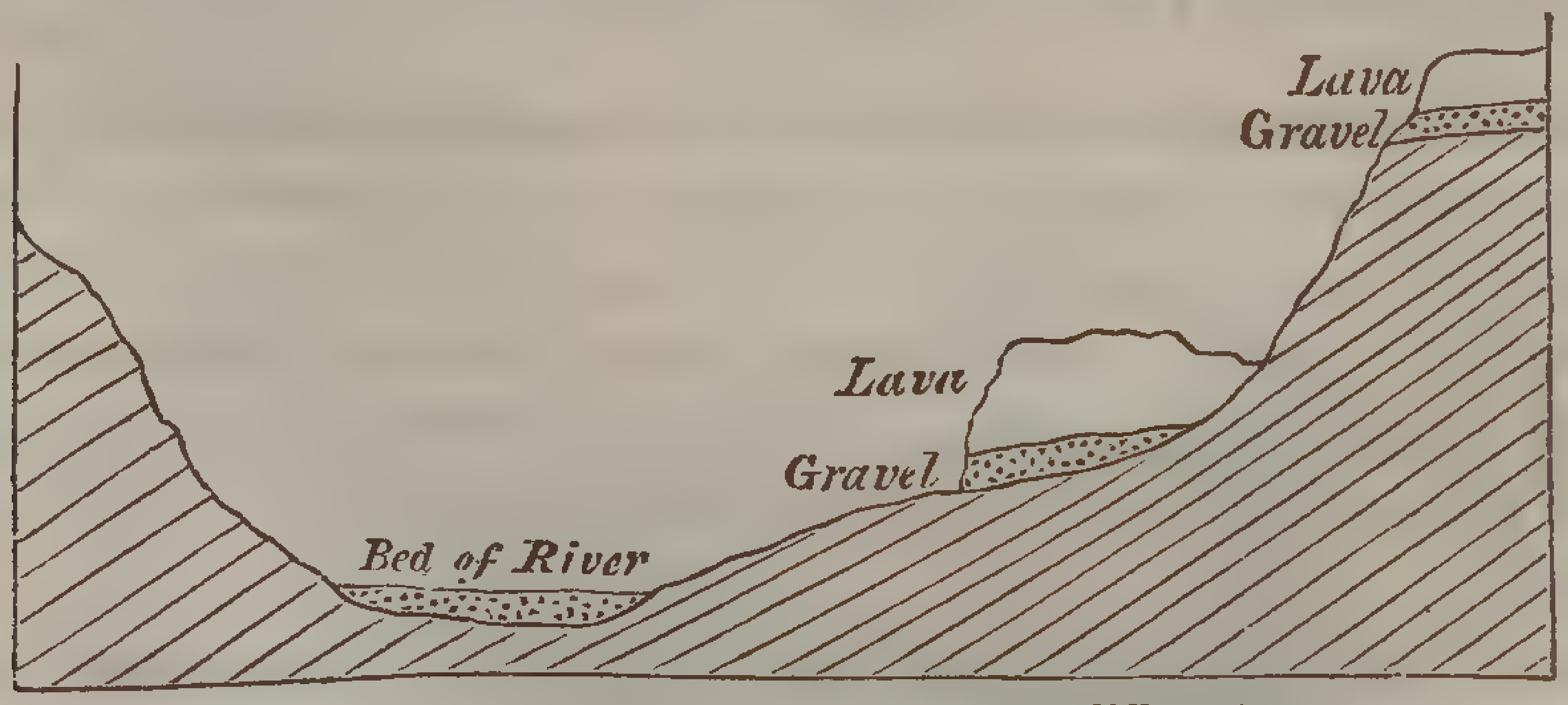
Alluvium described—Due to complicated causes—Of various ages, as shown in Auvergne—How distinguished from rocks *in situ*—River terraces—Parallel roads of Glen Roy—Various theories respecting their origin.

BETWEEN the superficial covering of vegetable mould and the subjacent rock there usually intervenes in every district a deposit of loose gravel, sand, and mud, to which the name of alluvium has been applied. The term is derived from *alluvio*, an inundation, or *alluo*, to wash, because the pebbles and sand commonly resemble those of a river's bed or the mud and gravel washed over low lands by a flood.

A partial covering of such alluvium is found alike in all climates, from the equatorial to the polar regions; but in the higher latitudes of Europe and North America it assumes a distinct character, being very frequently devoid of stratification, and containing huge fragments of rock, some angular and others rounded, which have been transported to great distances from their parent mountains. When it presents itself in this form, it has been called "diluvium," "drift," or the "boulder formation;" and its probable connexion with the agency of floating ice and glaciers will be treated of more particularly in the eleventh and twelfth chapters.

The student will be prepared, by what I have said in the last chapter on denudation, to hear that loose gravel and sand are often met with, not only on the low grounds bordering rivers, but also at various points on the sides or even summits of mountains. For, in the course of those changes in physical geography which may take place during the gradual emergence of the bottom of the sea and its conversion into dry land, any spot may either have been a sunken reef, or a bay, or estuary, or sea-shore, or the bed of a river. The drainage, moreover, may have been deranged again and again by earthquakes, during which temporary lakes are caused by landslips, and partial deluges occasioned by the bursting of the barriers of such lakes. For this reason it would be unreasonable to hope that we should ever be able to account for all the alluvial phenomena of each particular country, seeing that the causes of their origin are so various. Besides, the last operations of water have a tendency to disturb and confound together all pre-existing alluviums. Hence we are always in danger of regarding as the work of a single era, and the effect of one cause, what has in reality been the result of a variety of distinct agents, during a long succession of geological epochs. Much useful instruction may therefore be gained from the exploration of a country like Auvergne, where the superficial gravel of very different eras happens to have been preserved by sheets of lava, which were poured out one after the other at periods when the denudation, and probably the upheaval, of rocks were in progress. That region had already acquired in some degree its present configuration before any volcanoes were in activity, and before any igneous matter was superimposed upon the granitic and fossiliferous formations. The pebbles therefore in the older gravels are exclusively constituted of granite and other aboriginal rocks; and afterwards, when volcanic vents burst forth into eruption, those earlier alluviums were covered by streams of lava, which protected them from intermixture with gravel of subsequent date. In the course of ages, a new system of valleys was excavated, so that the rivers ran at lower levels than those at which the first alluviums and sheets of lava were formed. When, therefore, fresh eruptions gave rise to new lava, the melted matter was poured out over lower grounds; and the gravel of these plains

Fig. 99.



Lavas of Auvergne resting on alluviums of different ages.

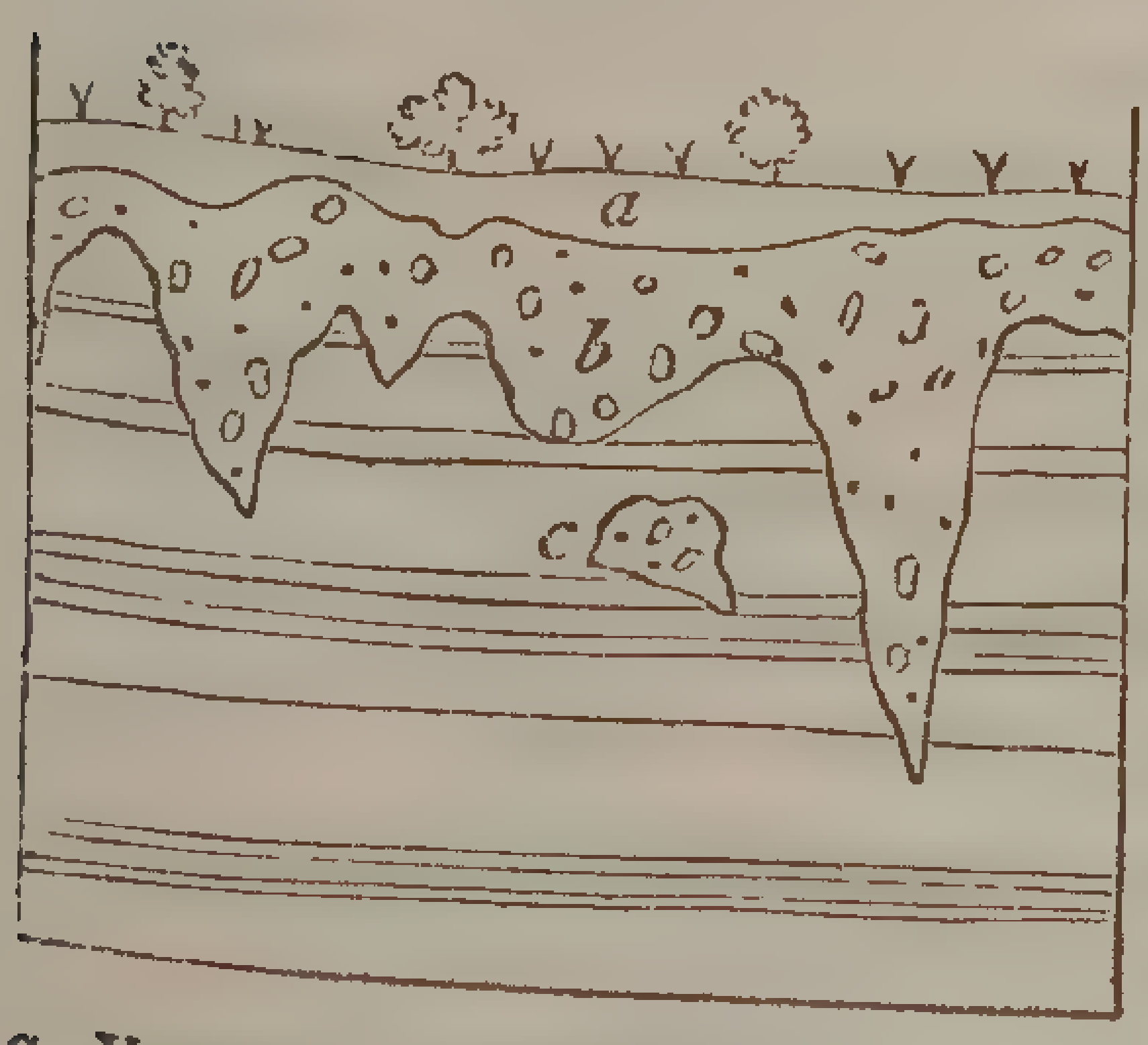
differed from the first or upland alluvium, by containing in it rounded fragments of various volcanic rocks, and often bones belonging to distinct groups of land animals which flourished in the country in succession.

The annexed drawing will explain the different heights at which beds of lava and gravel, each distinct from the other in composition and age, are observed, some on the flat tops of hills, 700 or 800 feet high, others on the slope of the same hills, and the newest of all in the channel of the existing river where there is usually gravel alone, but in some cases a narrow stripe of solid lava sharing the bottom of the valley with the river. In all these accumulations of transported matter of different ages the bones of extinct mammalia have been found belonging to assemblages of land quadrupeds, which flourished in the country in succession, and which vary specifically, the one set from the other, in a greater or less degree, in proportion as the time which separated their entombment has been more or less protracted. The streams in the same district are still undermining their banks and grinding down into pebbles or sand, columns of basalt and fragments of granite and gneiss; but portions of the older alluviums, with the fossil remains belonging to them, are prevented from being mingled with the gravel of recent date by the cappings of lava before mentioned. But for the accidental interference, therefore, of this peculiar cause, all the alluviums might have passed so insensibly the one into the other, that those formed at the remotest era might have appeared of the same date as the newest, and the whole formation might have been regarded by some geologists as the result of one sudden and violent catastrophe.

In almost every country, the alluvium consists in its upper part of transported materials, but it often passes downwards into a mass of broken and angular fragments derived from the subjacent rock. To this mass the provincial name of "rubble," or "brash," is given in many parts of England. It may be referred to the weathering or disintegration of stone on the spot, the effects of air and water, sun and frost, and chemical decomposition.

The inferior surface of alluvial deposits is often very irregular, conforming to all the inequalities of the fundamental rocks (fig. 100.). Occasionally, a small mass, as at *c*, appears detached, and as if included in the subjacent formation. Such isolated portions are usually sections of winding subterranean hollows filled up with alluvium. They may have been the courses of springs or subterranean streamlets, which have flowed through and enlarged natural rents; or, when on a small scale and in soft strata, they may be spaces which the roots of large trees have once occupied, gravel and sand having been introduced after their decay.

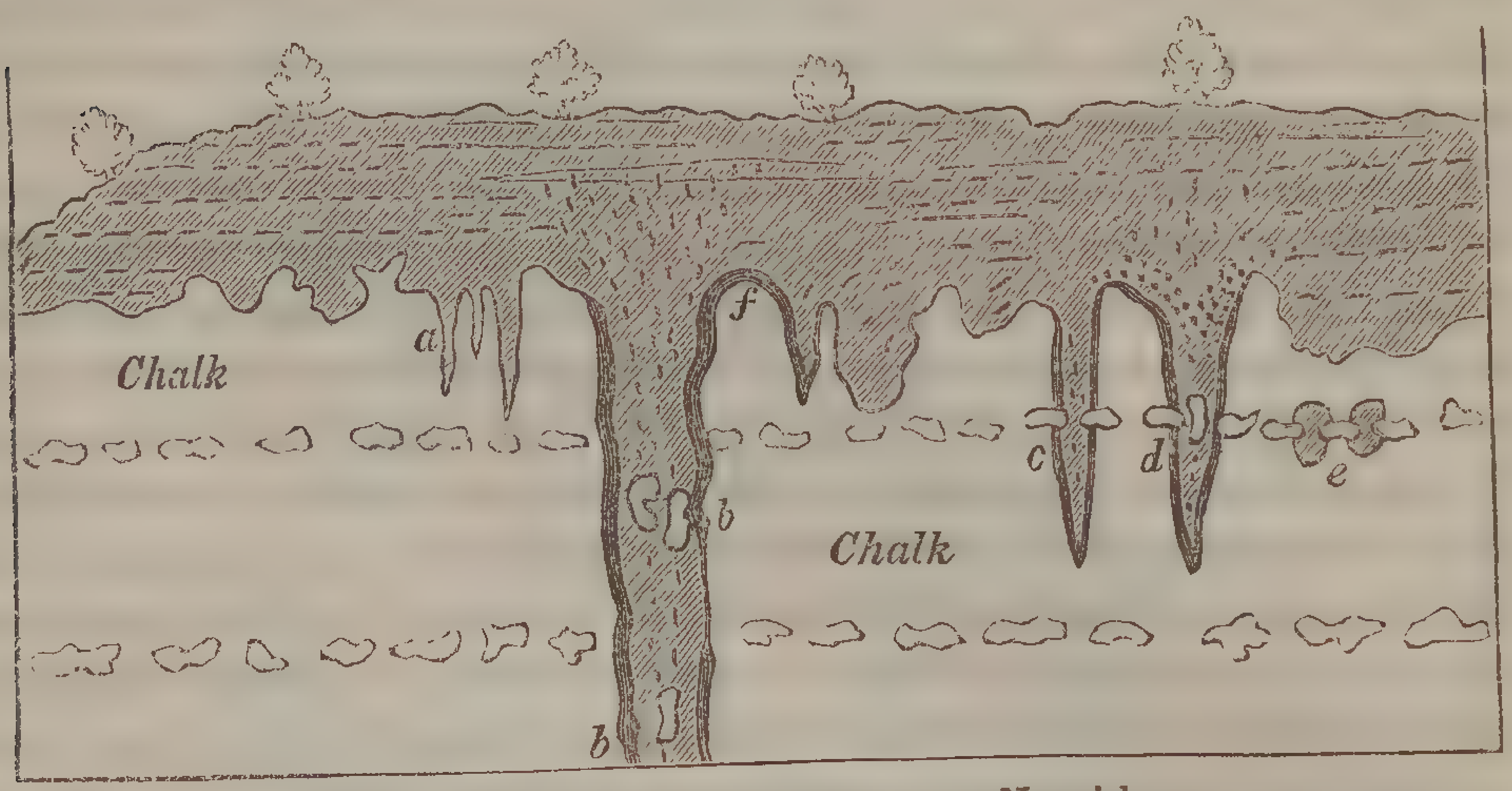
Fig. 100.



a. Vegetable soil. *b.* Alluvium.
c. Mass of same, apparently detached.

But there are other deep hollows of a cylindrical form found in England, France, and elsewhere, penetrating the white chalk, and filled with sand and gravel, which are not so readily explained. They are sometimes called "sand-pipes," or "sand-galls," and "puits naturels," in France. Those represented in the annexed cut were observed by me in 1839, laid open in a large chalk-pit near Norwich. They were of very symmetrical form, the largest more than 12 feet in diameter, and some of them had been traced, by boring, to the depth of more than 60 feet. The smaller ones varied from a few inches to a foot in diameter, and seldom descended more than 12 feet below the surface. Even where three of them occurred, as at *a*, fig. 101., very close together, the parting walls of soft white chalk were not broken through. They all taper downwards and end in a point. As a general rule, sand and pebbles occupy the central parts of each pipe, while the sides and bottom are lined with clay.

Fig. 101.



Sand-pipes in the chalk at Eaton, near Norwich.

Mr. Trimmer, in speaking of appearances of the same kind in the Kentish chalk, attributes the origin of such "sand-galls" to the action of the sea on a beach or shoal, where the waves, charged with shingle and sand, not only wear out longitudinal furrows, such as may be observed on the surface of the above-mentioned chalk near Norwich when the incumbent gravel is removed, but also drill deep circular hollows by the rotatory motion imparted to sand and pebbles. Such furrows, as well as vertical cavities, are now formed, he observes, on the coast where the shores are composed of chalk.*

That the commencement of many of the tubular cavities now under consideration has been due to the cause here assigned, I have little doubt. But such mechanical action could not have hollowed out the whole of the sand-pipes *c* and *d*, fig. 101., because several large chalk-flints seen protruding from the walls of the pipes have not been eroded, while sand and gravel have penetrated many feet below them. In other cases, as at *b b*, similar unrounded nodules of flint, still preserving their irregular form and white coating, are found at

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* Trimmer, Proceedings of Geol. Soc. vol. iv. p. 7. 1842.

various depths in the midst of the loose materials filling the pipe. These have evidently been detached from regular layers of flints occurring above. It is also to be remarked that the course of the same sand-pipe, *b b*, is traceable above the level of the chalk for some distance upwards, through the incumbent gravel and sand, by the obliteration of all signs of stratification. Occasionally, also, as in the pipe *d*, the overlying beds of gravel bend downwards into the mouth of the pipe, so as to become in part vertical, as would happen if horizontal layers had sunk gradually in consequence of a failure of support. All these phenomena may be accounted for by attributing the enlargement and deepening of the sand-pipes to the chemical action of water charged with carbonic acid, derived from the vegetable soil and the decaying roots of trees. Such acid might corrode the chalk, and deepen indefinitely any previously existing hollow, but could not dissolve the flints. The water, after it had become saturated with carbonate of lime, might freely percolate the surrounding porous walls of chalk, and escape through them and from the bottom of the tube, so as to carry away in the course of time large masses of dissolved calcareous rock *, and leave behind it on the edges of each tubular hollow a coating of fine clay, which the white chalk contains.

I have seen tubes precisely similar and from 1 to 5 feet in diameter traversing vertically the upper half of the soft calcareous building stone, or chalk without flints, constituting St. Peter's Mount, Maestricht. These hollows are filled with pebbles and clay, derived from overlying beds of gravel, and all terminate downwards like those of Norfolk. I was informed that, 6 miles from Maestricht, one of these pipes, 2 feet in diameter, was traced downwards to a bed of flattened flints, forming an almost continuous layer in the chalk. Here it terminated abruptly, but a few small root-like prolongations of it were detected immediately below, probably where the dissolving substance had penetrated at some points through openings in the siliceous mass.

It is not so easy as may at first appear to draw a clear line of distinction between the *fixed* rocks, or regular strata (rocks *in situ* or *in place*), and alluvium. If the bed of a torrent or river be dried up, we call the gravel, sand, and mud, left in their channels, or whatever, during floods, they may have scattered over the neighbouring plains, *alluvium.* The very same materials carried into a lake, where they become sorted by water and arranged in more distinct layers, especially if they inclose the remains of plants, shells, or other fossils, are termed regular strata.

In like manner we may sometimes compare the gravel, sand, and broken shells, strewed along the path of a rapid marine current, with a deposit formed contemporaneously by the discharge of similar materials year after year, into a deeper and more tranquil part of the sea. In such cases, when we detect marine shells or other organic remains entombed in the strata which enable us to determine their

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* See Lyell on Sand-pipes, &c., Phil Mag., third series, vol. xv. p. 257., Oct. 1839.

age and mode of origin, we regard them as part of the regular series of fossiliferous formations, whereas, if there are no fossils, we have frequently no power of separating them from the general mass of superficial alluvium.

The usual rarity of organic remains in beds of loose gravel is partly owing to the friction which originally ground down rocks into pebbles, or sand, and organic bodies into small fragments, and it is partly owing to the porous nature of alluvium when it has emerged, which allows the free percolation through it of rain-water, and promotes the decomposition and solution of fossil remains.

It has long been a matter of common observation that most rivers are now cutting their channels through alluvial deposits of greater depth and extent than could ever have been formed by the present streams. From this fact a rash inference has sometimes been drawn, that rivers in general have grown smaller, or become less liable to be flooded than formerly. But such phenomena would be a natural result of considerable oscillations in the level of the land experienced since the existing valleys originated.

Suppose part of a continent, comprising within it a large hydrographical basin like that of the Mississippi, to subside several inches or feet in a century, as the west coast of Greenland, extending 600 miles north and south, has been sinking for three or four centuries, between the latitudes 60° and 69° N.* It will rarely happen that the rate of subsidence will be everywhere equal, and in many cases the amount of depression in the interior will regularly exceed that of the region nearer the sea. Whenever this happens, the fall of the waters flowing from the upland country will be diminished, and each tributary stream will have less power to carry its sand and sediment into the main river, and the main river less power to convey its annual burden of transported matter to the sea. All the rivers, therefore, will proceed to fill up partially their ancient channels, and, during frequent inundations, will raise their alluvial plains by new deposits. If then the same area of land be again upheaved to its former height, the fall, and consequently the velocity, of every river will begin to augment. Each of them will be less given to overflow its alluvial plain; and their power of carrying earthy matter seaward, and of scouring out and deepening their channels, will be sustained till, after a lapse of many thousand years, each of them has eroded a new channel or valley through a fluviatile formation of comparatively modern date. The surface of what was once the river-plain at the period of greatest depression, will then remain fringing the valley-sides in the form of a terrace apparently flat, but in reality sloping down with the general inclination of the river. Everywhere this terrace will present cliffs of gravel and sand, facing the river. That such a series of movements has actually taken place in the main valley of the Mississippi and in its tributary valleys during oscillations of level, I have endeavoured to show in my description of that

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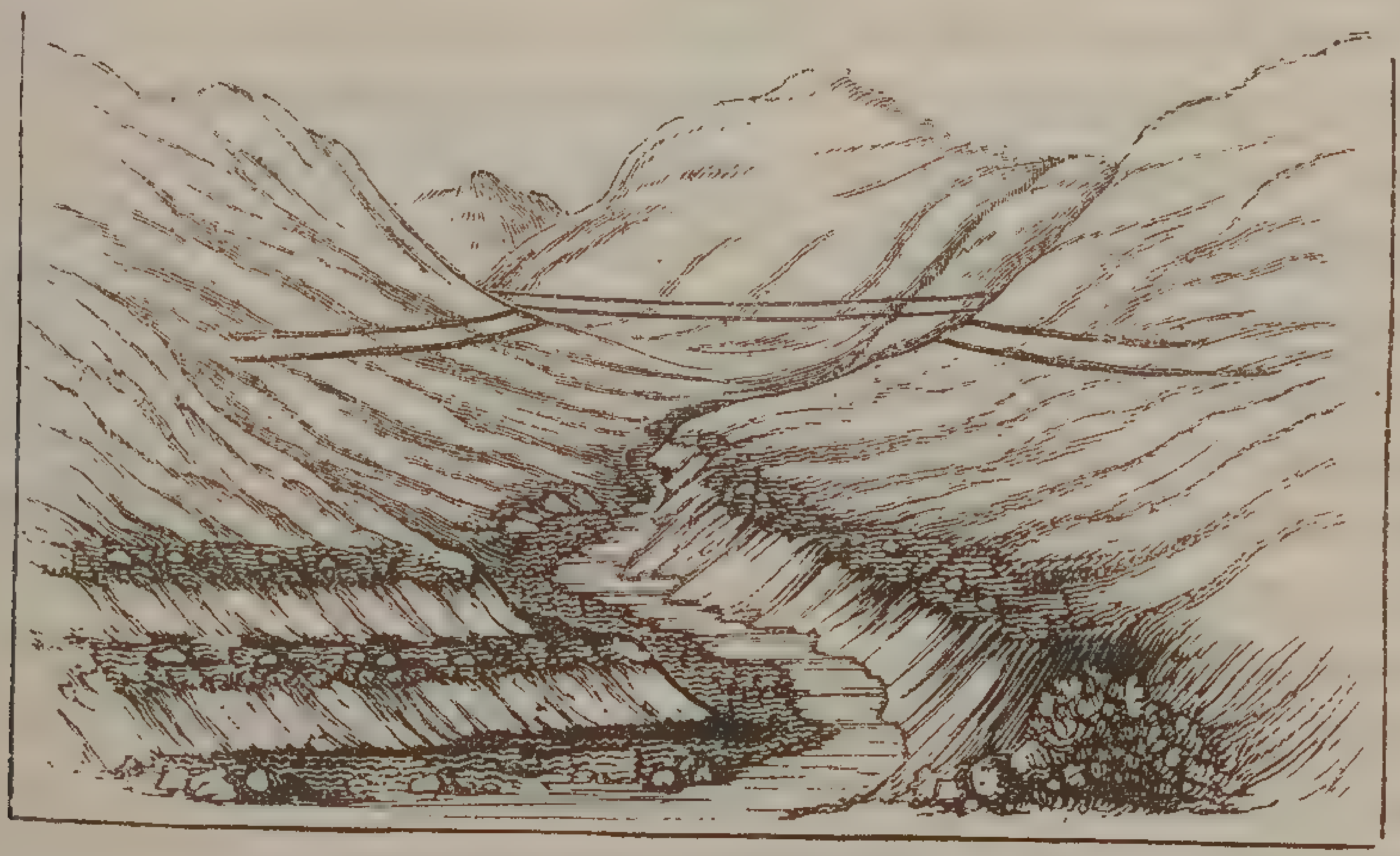
* Principles of Geology, 7th ed. p. 506., 8th ed. p. 509.

country*; and the freshwater shells of existing species and bones of land quadrupeds, partly of extinct races, preserved in the terraces of fluviatile origin, attest the exclusion of the sea during the whole process of filling up and partial re-excavation.

In many cases, the alluvium in which rivers are now cutting their channels, originated when the land first rose out of the sea. If, for example, the emergence was caused by a gradual and uniform motion, every bay and estuary, or the straits between islands, would dry up slowly, and during their conversion into valleys, every part of the upheaved area would in its turn be a sea-shore, and might be strewed over with littoral sand and pebbles, or each spot might be the point where a delta accumulated during the retreat and exclusion of the sea. Materials so accumulated would conform to the general slope of a valley from its head to the sea-coast.

River terraces.—We often observe at a short distance from the present bed of a river a steep cliff a few feet or yards high, and on a level with the top of it a flat terrace corresponding in appearance to the alluvial plain which immediately borders the river. This terrace is again bounded by another cliff, above which a second terrace sometimes occurs; and in this manner two or three ranges of cliffs and terraces are occasionally seen on one or both sides of the stream, the number varying, but those on the opposite sides often corresponding in height.

Fig. 102.



River Terraces and Parallel Roads.

These terraces are seldom continuous for great distances, and their surface slopes downwards with an inclination similar to that of the river. They are readily explained if we adopt the hypothesis before suggested, of a gradual rise of the land; especially if, while rivers are shaping out their beds, the upheaving movement be intermittent, so that long pauses shall occur, during which the stream will have time to encroach upon one of its banks, so as to clear away and flatten a large space. This operation being afterwards repeated at lower levels, there will be several successive cliffs and terraces.

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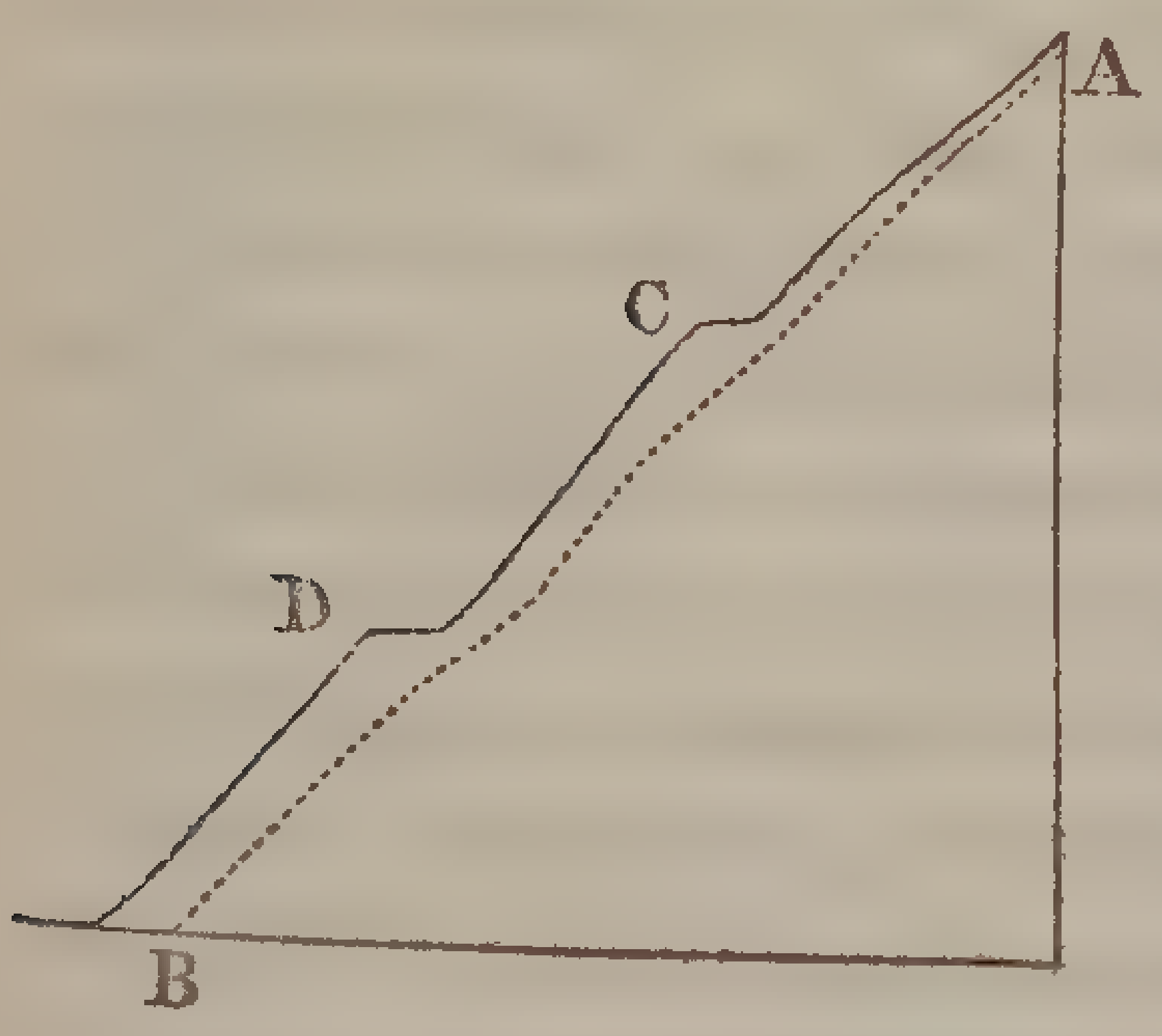
* Second Visit to the U. S. vol. ii. chap. 34.

Parallel roads.—The parallel shelves, or roads, as they have been called, of Lochaber or Glen Roy and other contiguous valleys in Scotland, are distinct both in character and origin from the terraces above described; for they have no slope towards the sea like the channel of a river, nor are they the effect of denudation. Glen Roy is situated in the Western Highlands, about ten miles north of Fort William, near the western end of the great glen of Scotland, or Caledonian Canal, and near the foot of the highest of the Grampians, Ben Nevis. Throughout its whole length, a distance of more than ten miles, two, and in its lower part three, parallel roads or shelves are traced along the steep sides of the mountains, as represented in the annexed figure, fig. 102., each maintaining a perfect horizontality, and continuing at exactly the same level on the opposite sides of the glen. Seen at a distance, they appear like ledges or roads, cut artificially out of the sides of the hills; but when we are upon them we can scarcely recognize their existence, so uneven is their surface, and so covered with boulders. They are from 10 to 60 feet broad, and merely differ from the side of the mountain by being somewhat less steep.

On closer inspection, we find that these terraces are stratified in the ordinary manner of alluvial or littoral deposits, as may be seen at those points where ravines have been excavated by torrents. The parallel shelves, therefore, have not been caused by denudation, but by the deposition of detritus, precisely similar to that which is dispersed in smaller quantities over the declivities of the hills above. These hills consist of clay-slate, mica-schist, and granite, which rocks have been worn away and laid bare at a few points only, in a line just above the parallel roads. The highest of these roads is about 1250 feet above the level of the sea, the next about 200 feet lower than the uppermost, and the third still lower by about 50 feet. It is only this last, or the lowest of the three, which is continued throughout Glen Spean, a large valley with which Glen Roy unites. As the shelves are always at the same height above the sea, they become continually more elevated above the river in proportion as we descend each valley; and they at length terminate very abruptly, without any obvious cause, or any change either in the shape of the ground or in the composition or hardness of the rocks. I should exceed the limits of this work, were I to attempt to give a full description of all the geographical circumstances attending these singular terraces, or to discuss the ingenious theories which have been severally proposed to account for them by Dr. Macculloch, Sir T. D. Lauder, and Messrs. Darwin, Agassiz, Milne, and Chambers. There is one point, however, on which all are agreed, namely, that these shelves are ancient beaches, or littoral formations accumulated round the edges of one or more sheets of water which once stood at the level, first of the highest shelf, and successively at the height of the two others. It is well known, that wherever a lake or marine fiord exists surrounded by steep mountains subject to disintegration by frost or the action of torrents, some loose matter is washed down annually, especially during the melting of snow, and a check is given to the descent of this detritus at the point where it reaches the waters of the lake. The waves then spread out the materials along the shore, and throw some of them upon the beach; their dispersing power being aided by the ice, which often adheres to pebbles during the winter months, and gives buoyancy to them. The annexed diagram illustrates the manner in which Dr. Macculloch and Mr. Darwin suppose "the roads" to constitute mere indentations in a superficial alluvial coating which rests upon the hill-side, and consists chiefly of clay and sharp unrounded stones.

Fig. 103.



A B. Supposed original surface of rock.
C D. Roads or shelves in the outer alluvial covering of the hill.

Among other proofs that the parallel roads have really been formed along the margin of a sheet of water, it may be mentioned, that wherever an isolated hill rises in the middle of the glen above the level of any particular shelf, a corresponding shelf is seen at the same level passing round the hill, as would have happened if it had once formed an island in a lake or fiord. Another very remarkable peculiarity in these terraces is this; each of them comes in some portion of its course to a *col*, or passage between the heads of glens, the explanation of which will be considered in the sequel.

Those writers who first advocated the doctrine that the roads were the ancient beaches of freshwater lakes, were unable to offer any probable hypothesis respecting the formation and subsequent removal of barriers of sufficient height and solidity to dam up the water. To introduce any violent convulsion for their removal was inconsistent with the uninterrupted horizontality of the roads, and with the undisturbed aspect of those parts of the glens where the shelves come suddenly to an end. Mr. Agassiz and Dr. Buckland, desirous, like the defenders of the lake theory, to account for the limitation of the shelves to certain glens, and their absence in contiguous glens, where the rocks are of the same composition, and the slope and inclination of the ground very similar, started the conjecture that these valleys were once blocked up by enormous glaciers descending from Ben Nevis, giving rise to what are called in Switzerland and in the Tyrol, glacier-lakes. After a time the icy barrier was broken down, or melted, first, to the level of the second, and afterwards to that of the third road or shelf.

In corroboration of this view, they contended that the alluvium of Glen Roy, as well as of other parts of Scotland, agrees in character with the moraines of glaciers seen in the Alpine valleys of Switzerland. Allusion will be made in the eleventh chapter to the former existence of glaciers in the Grampians: in the mean time it will readily be conceded that this hypothesis is preferable to any previous lacustrine theory, by accounting more easily for the temporary existence and entire disappearance of lofty transverse barriers, although the height required for the imaginary dams of ice may be startling.

Before the idea last alluded to had been entertained, Mr. Darwin examined Glen Roy, and came to the opinion that the shelves were formed when the glens were still arms of the sea, and, consequently, that there never were any seaward barriers. According to him, the land emerged during a slow and uniform upward movement, like that now experienced throughout a large part of Sweden and Finland; but there were certain pauses in the upheaving process, at which times the waters of the sea remained stationary for so many centuries as to allow of the accumulation of an extraordinary quantity of detrital matter, and the excavation, at many points immediately above, of deep notches and bare cliffs in the hard and solid rock.

The phenomena which are most difficult to reconcile with this theory are, first, the abrupt cessation of the roads at certain points in the different glens; secondly, their unequal number in different valleys connecting with each other, there being three, for example, in Glen Roy and only one in Glen Spean; thirdly, the precise horizontality of level maintained by the same shelf over a space many leagues in length requiring us to assume, that during a rise of 1250 feet no one portion of the land was raised even a few yards above another; fourthly, the coincidence of level already alluded to of each shelf with a *col*, or the point forming the head of two glens, from which the rain-waters flow in opposite directions. This last-mentioned feature in the physical geography of Lochaber seems to have been explained in a satisfactory manner by Mr. Darwin. He calls these *cols* "landstraits," and regards them as having been anciently sounds or channels between islands. He points out that there is a tendency in such sounds to be silted up, and always the more so in proportion to their narrowness. In a chart of the Falkland Islands, by Capt. Sullivan, R. N., it appears that there are several examples there of straits where the soundings diminish regularly towards the narrowest part. One is so nearly dry that it can be walked over at low water, and another, no longer covered by the sea, is supposed to have recently dried up in consequence of a small alteration in the relative level of sea and land. "Similar straits," observes Mr. Chambers, "hovering, in character, between sea and land, and which may be called fords, are met with in the Hebrides. Such, for example, is the passage dividing the islands of Lewis and Harris, and that between North Uist and Benbecula, both of which would undoubtedly appear as *cols*, coinciding with a terrace or raised beach, all round the islands, if the sea were to subside."*

The first of the difficulties above alluded to, namely, the non-extension of the shelves over certain parts of the glens, may be explained, as Mr. Darwin suggests, by supposing in certain places a quick growth of green turf on a good soil, which prevented the rain from washing away any loose materials lying on the surface. But wherever the soil was barren, and where green sward took long to form, there may

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* "Ancient Sea Margins," p. 114., by R. Chambers.

have been time for the removal of the gravel. In one case an intermediate shelf appears for a short distance (three quarters of a mile) on the face of the mountain called Tombhran, between the two upper shelves, and is seen nowhere else. It occurs where there was the longest space of open water, and where, perhaps, the waves acquired a greater than ordinary power in heaping up detritus.

Next as to the precise horizontality of level maintained by the parallel roads of Lochaber over an area many leagues in length and breadth, this is a difficulty common in some degree to all the rival hypotheses, whether of lakes, or glaciers, or of the simple upheaval of the land above the sea. For we cannot suppose the roads to be more ancient than the glacial period, or the era of the boulder formation of Scotland, of which I shall speak in the eleventh and twelfth chapters. Strata of that era of marine origin containing northern shells of existing species have been found at various heights in Scotland, some on the east, and others on the west coast, from 20 to 400 feet high; and in one region in Lanarkshire not less than 524 feet above high-water mark. It seems, therefore, in the highest degree improbable that Glen Roy should have escaped entirely the upward movement experienced in so many surrounding regions,—a movement implied by the position of these marine deposits, in which the shells are almost all of known recent species. But if the motion has really extended to Glen Roy and the contiguous glens, it must have uplifted them bodily, without in the slightest degree affecting their horizontality; and this being admitted, the principal objection to the theory of marine beaches, founded on the uniformity of upheaval, is removed, or is at least common to every theory hitherto proposed.

To assume that the ocean has gone down from the level of the uppermost shelf, or 1250 feet, simultaneously all over the globe, while the land remained unmoved, is a view which will find favour with very few geologists, for the reasons explained in the fifth chapter.

The student will perceive, from the above sketch of the controversy respecting the formation of these curious shelves, that this problem, like many others in geology, is as yet only solved in part; and that a larger number of facts must be collected and reasoned upon before the question can be finally settled.

CHAPTER VIII.

CHRONOLOGICAL CLASSIFICATION OF ROCKS.

Aqueous, plutonic, volcanic, and metamorphic rocks, considered chronologically—Lehman's division into primitive and secondary—Werner's addition of a transition class—Neptunian theory—Hutton on igneous origin of granite—How the name of primary was still retained for granite—The term "transition," why faulty—The adherence to the old chronological nomenclature retarded the progress of geology—New hypothesis invented to reconcile the igneous origin of granite to the notion of its high antiquity—Explanation of the chronological nomenclature adopted in this work, so far as regards primary, secondary, and tertiary periods.

In the first chapter it was stated that the four great classes of rocks, the aqueous, the volcanic, the plutonic, and the metamorphic, would each be considered not only in reference to their mineral characters, and mode of origin, but also to their relative age. In regard to the aqueous rocks, we have already seen that they are stratified, that some are calcareous, others argillaceous or siliceous, some made up of sand, others of pebbles; that some contain freshwater, others marine fossils, and so forth; but the student has still to learn which rocks, exhibiting some or all of these characters, have originated at one period of the earth's history, and which at another.

To determine this point in reference to the fossiliferous formations is more easy than in any other class, and it is therefore the most convenient and natural method to begin by establishing a chronology for these strata, and then to refer as far as possible to the same divisions, the several groups of plutonic, volcanic, and metamorphic rocks. Such a system of classification is not only recommended by its greater clearness and facility of application, but is also best fitted to strike the imagination by bringing into one view the contemporaneous revolutions of the inorganic and organic creations of former times. For the sedimentary formations are most readily distinguished by the different species of fossil animals and plants which they inclose, and of which one assemblage after another has flourished and then disappeared from the earth in succession.

But before entering specially on the subdivisions of the aqueous rocks arranged according to the order of time, it will be desirable to say a few words on the chronology of rocks in general, although in doing so we shall be unavoidably led to allude to some classes of phenomena which the beginner must not yet expect fully to comprehend.

It was for many years a received opinion that the formation of entire families of rocks, such as the plutonic and those crystalline schists spoken of in the first chapter as metamorphic, began and ended before any members of the aqueous and volcanic orders were produced; and although this idea has long been modified, and is nearly exploded, it will be necessary to give some account of the ancient doctrine, in order that beginners may understand whence many prevailing opinions, and some part of the nomenclature of geology, still partially in use, was derived.

About the middle of the last century, Lehman, a German miner, proposed to divide rocks into three classes, the first and oldest to be called primitive, comprising the hypogene, or plutonic and metamorphic rocks; the next to be termed secondary, comprehending the aqueous or fossiliferous strata; and the remainder, or third class, corresponding to our alluvium, ancient and modern, which he referred to "local floods, and the deluge of Noah." In the primitive class, he said, such as granite and gneiss, there are no organic remains, nor any signs of materials derived from the ruins of pre-existing rocks. Their origin, therefore, may have been purely chemical, antecedent to the creation of living beings, and probably coeval with the birth of the world itself. The secondary formations, on the contrary, which often contain sand, pebbles, and organic remains, must have been mechanical deposits, produced after the planet had become the habitation of animals and plants. This bold generalization, although anticipated in some measure by Steno, a century before, in Italy, formed at the time an important step in the progress of geology, and sketched out correctly some of the leading divisions into which rocks may be separated. About half a century later, Werner, so justly celebrated for his improved methods of discriminating the mineralogical characters of rocks, attempted to improve Lehman's classification, and with this view intercalated a class, called by him "the transition formations," between the primitive and secondary. Between these last he had discovered, in northern Germany, a series of strata, which in their mineral peculiarities were of an intermediate character, partaking in some degree of the crystalline nature of micaceous schist and clay-slate, and yet exhibiting here and there signs of a mechanical origin and organic remains. For this group, therefore, forming a passage between Lehman's primitive and secondary rocks, the name of *übergang* or transition was proposed. They consisted principally of clay-slate and an argillaceous sandstone, called grauwacke, and partly of calcareous beds. It happened in the district which Werner first investigated, that both the primitive and transition strata were highly inclined, while the beds of the newer fossiliferous rocks, the secondary of Lehman, were horizontal. To these latter, therefore, he gave the name of *flötz*, or "a level floor;" and every deposit more modern than the chalk, which was classed as the uppermost of the flötz series, was designated "the overflowed land," an expression which may be regarded as equivalent to alluvium, although under this appellation were confounded all the strata afterwards called tertiary, of which Werner had scarcely any knowledge. As the followers of Werner soon discovered that the inclined position of the "transition beds," and the horizontality of the flötz, or newer fossiliferous strata, were mere local accidents, they soon abandoned the term flötz; and the four divisions of the Wernerian school were then named primitive, transition, secondary, and alluvial.

As to the trappean rocks, although their igneous origin had been already demonstrated by Arduino, Fortis, Faujas, and others, and especially by Desmarest, they were all regarded by Werner as aqueous, and as mere subordinate members of the secondary series.*

This theory of Werner's was called the "Neptunian," and for many years enjoyed much popularity. It assumed that the globe had been at first invested by an universal chaotic ocean, holding the materials of all rocks in solution. From the waters of this ocean, granite, gneiss, and other crystalline formations, were first precipitated; and afterwards, when the waters were purged of these ingredients, and more nearly resembled those of our actual seas, the transition strata were deposited. These were of a mixed character, not purely chemical, because the waves and currents had already begun to wear down solid land, and to give rise to pebbles, sand, and mud; nor entirely without fossils, because a few of the first marine animals had begun to exist. After this period, the secondary formations were accumulated in waters resembling those of the present ocean, except at certain intervals, when, from causes wholly unexplained, a partial recurrence of the "chaotic fluid" took place, during which various trap rocks, some highly crystalline, were formed. This arbitrary hypothesis rejected all intervention of igneous agency, volcanos being regarded as modern, partial, and superficial accidents, of trifling account among the great causes which have modified the external structure of the globe.

Meanwhile Hutton, a contemporary of Werner, began to teach, in Scotland, that granite as well as trap was of igneous origin, and had at various periods intruded itself in a fluid state into different parts of the earth's crust. He recognized and faithfully described many of the phenomena of granitic veins, and the alterations produced by them on the invaded strata, which will be treated of in the thirty-third chapter. He, moreover, advanced the opinion, that the crystalline strata called primitive had not been precipitated from a primæval ocean, but were sedimentary strata altered by heat. In his writings, therefore, and in those of his illustrator, Playfair, we find the germ of that metamorphic theory which has been already hinted at in the first chapter, and which will be more fully expounded in the thirty-fourth and thirty-fifth chapters.

At length, after much controversy, the doctrine of the igneous origin of trap and granite made its way into general favour; but although it was, in consequence, admitted that both granite and trap had been produced at many successive periods, the term primitive or primary still continued to be applied to the crystalline formations in general, whether stratified, like gneiss, or unstratified, like granite. The pupil was told that granite was a primary rock, but that some granites were newer than certain secondary formations; and in con-

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* See Principles of Geology, vol. i. chap. iv.

formity with the spirit of the ancient language, to which the teacher was still determined to adhere, a desire was naturally engendered of extenuating the importance of those more modern granites, the true dates of which new observations were continually bringing to light.

A no less decided inclination was shown to persist in the use of the term "transition," after it had been proved to be almost as faulty in its original application as that of flötz. The name of transition, as already stated, was first given by Werner, to designate a mineral character, intermediate between the highly crystalline or metamorphic state and that of an ordinary fossiliferous rock. But the term acquired also from the first a chronological import, because it had been appropriated to sedimentary formations, which, in the Hartz and other parts of Germany, were more ancient than the oldest of the secondary series, and were characterized by peculiar fossil zoophytes and shells. When, therefore, geologists found in other districts stratified rocks occupying the same position, and inclosing similar fossils, they gave to them also the name of *transition,* according to rules which will be explained in the next chapter; yet, in many cases, such rocks were found not to exhibit the same mineral texture which Werner had called transition. On the contrary, many of them were not more crystalline than different members of the secondary class; while, on the other hand, these last were sometimes found to assume a semi-crystalline and almost metamorphic aspect, and thus, on lithological grounds, to deserve equally the name of transition. So remarkably was this the case in the Swiss Alps, that certain rocks, which had for years been regarded by some of the most skilful disciples of Werner to be transition, were at last acknowledged, when their relative position and fossils were better understood, to belong to the newest of the secondary groups; nay, some of them have actually been discovered to be members of the lower tertiary series! If, under such circumstances, the name of transition was retained, it is clear that it ought to have been applied without reference to the age of strata, and simply as expressive of a mineral peculiarity. The continued appropriation of the term to formations of a given date, induced geologists to go on believing that the ancient strata so designated bore a less resemblance to the secondary than is really the case, and to imagine that these last never pass, as they frequently do, into metamorphic rocks.

The poet Waller, when lamenting over the antiquated style of Chaucer, complains that —

> We write in sand, our language grows,
> And, like the tide, our work o'erflows.

But the reverse is true in geology; for here it is our work which continually outgrows the language. The tide of observation advances with such speed that improvements in theory outrun the changes of nomenclature; and the attempt to inculcate new truths by words invented to express a different or opposite opinion, tends constantly, by the force of association, to perpetuate error; so that dogmas renounced by the reason still retain a strong hold upon the imagination.

In order to reconcile the old chronological views with the new doctrine of the igneous origin of granite, the following hypothesis was substituted for that of the Neptunists. Instead of beginning with an aqueous menstruum or chaotic fluid, the materials of the present crust of the earth were supposed to have been at first in a state of igneous fusion, until part of the heat having been diffused into surrounding space, the surface of the fluid consolidated, and formed a crust of granite. This covering of crystalline stone, which afterwards grew thicker and thicker as it cooled, was so hot, at first, that no water could exist upon it; but as the refrigeration proceeded, the aqueous vapour in the atmosphere was condensed, and, falling in rain, gave rise to the first *thermal ocean.* So high was the temperature of this boiling sea, that no aquatic beings could inhabit its waters, and its deposits were not only devoid of fossils, but, like those of some hot springs, were highly crystalline. Hence the origin of the primary or crystalline strata,—gneiss, mica-schist, and the rest.

Afterwards, when the granitic crust had been partially broken up, land and mountains began to rise above the waters, and rains and torrents to grind down rock, so that sediment was spread over the bottom of the seas. Yet the heat still remaining in the solid supporting substances was sufficient to increase the chemical action exerted by the water, although not so intense as to prevent the introduction and increase of some living beings. During this state of things some of the residuary mineral ingredients of the primæval ocean were precipitated, and formed deposits (the transition strata of Werner), half chemical and half mechanical, and containing a few fossils.

By this new theory, which was in part a revival of the doctrine of Leibnitz, published in 1680, on the igneous origin of the planet, the old ideas respecting the priority of all crystalline rocks to the creation of organic beings, were still preserved; and the mistaken notion that all the semi-crystalline and partially fossiliferous rocks belonged to one period, while all the earthy and uncrystalline formations originated at a subsequent epoch, was also perpetuated.

It may or may not be true, as the great Leibnitz imagined, that the whole planet was once in a state of liquefaction by heat; but there are certainly no geological proofs that the granite which constitutes the foundation of so much of the earth's crust was ever at once in a state of universal fusion. On the contrary, all our evidence tends to show that the formation of granite, like the deposition of the stratified rocks, has been successive, and that different portions of granite have been in a melted state at distinct and often distant periods. One mass was solid, and had been fractured, before another body of granitic matter was injected into it, or through it, in the form of veins. Some granites are more ancient than any known fossiliferous rocks; others are of secondary; and some, such as that of Mont Blanc and part of the central axis of the Alps, of tertiary origin. In short, the universal fluidity of the crystalline foundations of the earth's crust, can only be understood in the same sense as the universality of the ancient ocean. All the land has been under water, but not all at one time; so all the subterranean unstratified rocks to which man can obtain access have been melted, but not simultaneously.

In the present work the four great classes of rocks, the aqueous, plutonic, volcanic, and metamorphic, will form four parallel, or nearly parallel, columns in one chronological table. They will be considered as four sets of monuments relating to four contemporaneous, or nearly contemporaneous, series of events. I shall endeavour, in a subsequent chapter on the plutonic rocks, to explain the manner in which certain masses belonging to each of the four classes of rocks may have originated simultaneously at every geological period, and how the earth's crust may have been continually remodelled, above and below, by aqueous and igneous causes, from times indefinitely remote. In the same manner as aqueous and fossiliferous strata are now formed in certain seas or lakes, while in other places volcanic rocks break out at the surface, and are connected with reservoirs of melted matter at vast depths in the bowels of the earth, — so, at every era of the past, fossiliferous deposits and superficial igneous rocks were in progress contemporaneously with others of subterranean and plutonic origin, and some sedimentary strata were exposed to heat, and made to assume a crystalline or metamorphic structure.

It can by no means be taken for granted, that during all these changes the solid crust of the earth has been increasing in thickness. It has been shown, that so far as aqueous action is concerned, the gain by fresh deposits, and the loss by denudation, must at each period have been equal (see above, p. 68.); and in like manner, in the inferior portion of the earth's crust, the acquisition of new crystalline rocks, at each successive era, may merely have counterbalanced the loss sustained by the melting of materials previously consolidated. As to the relative antiquity of the crystalline foundations of the earth's crust, when compared to the fossiliferous and volcanic rocks which they support, I have already stated, in the first chapter, that to pronounce an opinion on this matter is as difficult as at once to decide which of the two, whether the foundations or superstructure of an ancient city built on wooden piles, may be the oldest. We have seen that, to answer this question, we must first be prepared to say whether the work of decay and restoration had gone on most rapidly above or below; whether the average duration of the piles has exceeded that of the stone buildings, or the contrary. So also in regard to the relative age of the superior and inferior portions of the earth's crust; we cannot hazard even a conjecture on this point, until we know whether, upon an average, the power of water above, or that of heat below, is most efficacious in giving new forms to solid matter.

After the observations which have now been made, the reader will perceive that the term primary must either be entirely renounced, or, if retained, must be differently defined, and not made to designate a set of crystalline rocks, some of which are already ascertained to be newer than all the secondary formations. In this work I shall follow most nearly the method proposed by Mr. Boué, who has called all *fossiliferous* rocks older than the secondary by the name of primary. To prevent confusion, I shall sometimes speak of these last as the *primary fossiliferous* formations; because the word primary has hitherto been most generally connected with the idea of a non-fossiliferous rock. Some geologists, to avoid misapprehension, have introduced the term Paleozoic for primary, from *παλαιον*, "ancient," and *ζωον*, "an organic being," still retaining the terms secondary and tertiary; Mr. Phillips, for the sake of uniformity, has proposed Mesozoic, for secondary, from *μεσος*, "middle," &c.; and Cainozoic, for tertiary, from *καινος*, "recent," &c.; but the terms primary, secondary, and tertiary are synonymous, and have the claim of priority in their favour.

If we can prove any plutonic, volcanic, or metamorphic rocks to be older than the secondary formations, such rocks will also be primary, according to this system. Mr. Boué having with propriety excluded the metamorphic rocks, *as a class*, from the primary formations, proposed to call them all "crystalline schists."

As there are secondary fossiliferous strata, so we shall find that there are plutonic, volcanic, and metamorphic rocks of contemporaneous origin, which I shall also term secondary.

In the next chapter it will be shown that the strata above the chalk have been called tertiary. If, therefore, we discover any volcanic, plutonic, or metamorphic rocks, which have originated since the deposition of the chalk, these also will rank as tertiary formations.

It may perhaps be suggested that some metamorphic strata, and some granites, may be anterior in date to the oldest of the primary fossiliferous rocks. This opinion is doubtless true, and will be discussed in future chapters; but I may here observe, that when we arrange the four classes of rocks in four parallel columns in one table of chronology, it is by no means assumed that these columns are all of equal length; one may begin at an earlier period than the rest, and another may come down to a later point of time. In the small part of the globe hitherto examined, it is hardly to be expected that we should have discovered either the oldest or the newest members of each of the four classes of rocks. Thus, if there be primary, secondary, and tertiary rocks of the aqueous or fossiliferous class, and in like manner primary, secondary, and tertiary hypogene formations, we may not be yet acquainted with the most ancient of the primary fossiliferous beds, or with the newest of the hypogene.

CHAPTER IX.

ON THE DIFFERENT AGES OF THE AQUEOUS ROCKS.

On the three principal tests of relative age — superposition, mineral character, and fossils — Change of mineral character and fossils in the same continuous formation — Proofs that distinct species of animals and plants have lived at successive periods — Distinct provinces of indigenous species — Great extent of single provinces — Similar laws prevailed at successive geological periods — Relative importance of mineral and palæontological characters — Test of age by included fragments — Frequent absence of strata of intervening periods — Principal groups of strata in western Europe.

IN the last chapter I spoke generally of the chronological relations of the four great classes of rocks, and I shall now treat of the aqueous rocks in particular, or of the successive periods at which the different fossiliferous formations have been deposited.

There are three principal tests by which we determine the age of a given set of strata; first, superposition; secondly, mineral character; and, thirdly, organic remains. Some aid can occasionally be derived from a fourth kind of proof, namely, the fact of one deposit including in it fragments of a pre-existing rock, by which the relative ages of the two may, even in the absence of all other evidence, be determined.

Superposition. — The first and principal test of the age of one aqueous deposit, as compared to another, is relative position. It has been already stated, that, where strata are horizontal, the bed which lies uppermost is the newest of the whole, and that which lies at the bottom the most ancient. So, of a series of sedimentary formations, they are like volumes of history, in which each writer has recorded the annals of his own times, and then laid down the book, with the last written page uppermost, upon the volume in which the events of the era immediately preceding were commemorated. In this manner a lofty pile of chronicles is at length accumulated; and they are so arranged as to indicate, by their position alone, the order in which the events recorded in them have occurred.

In regard to the crust of the earth, however, there are some regions where, as the student has already been informed, the beds have been disturbed, and sometimes extensively thrown over and turned upside down. (See pp. 58, 59.) But an experienced geologist can rarely be deceived by these exceptional cases. When he finds that the strata are fractured, curved, inclined, or vertical, he knows that the original order of superposition must be doubtful, and he then endeavours to find sections in some neighbouring district where the strata are horizontal, or only slightly inclined. Here, the true order of sequence of the entire series of deposits being ascertained, a key is furnished for settling the chronology of those strata where the displacement is extreme.

Mineral character.—The same rocks may often be observed to retain for miles, or even hundreds of miles, the same mineral peculiarities, if we follow the planes of stratification, or trace the beds, if they be undisturbed, in a horizontal direction. But if we pursue them vertically, or in any direction transverse to the planes of stratification, this uniformity ceases almost immediately. In that case we can scarcely ever penetrate a stratified mass for a few hundred yards without beholding a succession of extremely dissimilar rocks, some of fine, others of coarse grain, some of mechanical, others of chemical origin; some calcareous, others argillaceous, and others siliceous. These phenomena lead to the conclusion, that rivers and currents have dispersed the same sediment over wide areas at one period, but at successive periods have been charged, in the same region, with very different kinds of matter. The first observers were so astonished at the vast spaces over which they were able to follow the same homogeneous rocks in a horizontal direction, that they came hastily to the opinion, that the whole globe had been environed by a succession of distinct aqueous formations, disposed round the nucleus of the planet, like the concentric coats of an onion. But although, in fact, some formations may be continuous over districts as large as half of Europe, or even more, yet most of them either terminate wholly within narrower limits, or soon change their lithological character. Sometimes they thin out gradually, as if the supply of sediment had failed in that direction, or they come abruptly to an end, as if we had arrived at the borders of the ancient sea or lake which served as their receptacle. It no less frequently happens that they vary in mineral aspect and composition, as we pursue them horizontally. For example, we trace a limestone for a hundred miles, until it becomes more arenaceous, and finally passes into sand, or sandstone. We may then follow this sandstone, already proved by its continuity to be of the same age, throughout another district a hundred miles or more in length.

Organic remains.—This character must be used as a criterion of the age of a formation or of the contemporaneous origin of two deposits in distant places, under very much the same restrictions as the test of mineral composition.

First, the same fossils may be traced over wide regions, if we examine strata in the direction of their planes, although by no means for indefinite distances.

Secondly, while the same fossils prevail in a particular set of strata for hundreds of miles in a horizontal direction, we seldom meet with the same remains for many fathoms, and very rarely for several hundred yards, in a vertical line, or a line transverse to the strata. This fact has now been verified in almost all parts of the globe, and has led to a conviction, that at successive periods of the past, the same area of land and water has been inhabited by species of animals and plants even more distinct than those which now people the antipodes, or which now co-exist in the arctic, temperate, and tropical zones. It appears, that from the remotest periods there has been ever a coming in of new organic forms, and an extinction of those which pre-existed on the earth; some species having endured for a longer, others for a shorter, time; while none have ever re-appeared after once dying out. The law which has governed the creation and extinction of species seems to be expressed in the verse of the poet,—

> Natura il fece, e poi ruppe la stampa. ARIOSTO.
> Nature made him, and then broke the die.

And this circumstance it is, which confers on fossils their highest value as chronological tests, giving to each of them, in the eyes of the geologist, that authority which belongs to contemporary medals in history.

The same cannot be said of each peculiar variety of rock; for some of these, as red marl and red sandstone, for example, may occur at once at the top, bottom, and middle of the entire sedimentary series; exhibiting in each position so perfect an identity of mineral aspect as to be undistinguishable. Such exact repetitions, however, of the same mixtures of sediment have not often been produced, at distant periods, in precisely the same parts of the globe; and, even where this has happened, we are seldom in any danger of confounding together the monuments of remote eras, when we have studied their imbedded fossils and their relative position.

It was remarked that the same species of organic remains cannot be traced horizontally, or in the direction of the planes of stratification for indefinite distances. This might have been expected from analogy; for when we inquire into the present distribution of living beings we find that the habitable surface of the sea and land may be divided into a considerable number of distinct provinces, each peopled by a peculiar assemblage of animals and plants. In the Principles of Geology, I have endeavoured to point out the extent and probable origin of these separate divisions; and it was shown that climate is only one of many causes on which they depend, and that difference of longitude as well as latitude is generally accompanied by a dissimilarity of indigenous species.

As different seas, therefore, and lakes are inhabited, at the same period, by different aquatic animals and plants, and as the lands adjoining these may be peopled by distinct terrestrial species, it follows that distinct fossils will be imbedded in contemporaneous deposits. If it were otherwise—if the same species abounded in every climate, or in every part of the globe where, so far as we can discover, a corresponding temperature and other conditions favourable to their existence are found—the identification of mineral masses of the same age, by means of their included organic contents, would be a matter of still greater certainty.

Nevertheless, the extent of some single zoological provinces, especially those of marine animals, is very great; and our geological researches have proved that the same laws prevailed at remote periods; for the fossils are often identical throughout wide spaces, and in detached deposits, consisting of rocks varying entirely in their mineral nature.

The doctrine here laid down will be more readily understood, if we reflect on what is now going on in the Mediterranean. That entire sea may be considered as one zoological province; for although certain species of testacea and zoophytes may be very local, and each region has probably some species peculiar to it, still a considerable number are common to the whole Mediterranean. If, therefore, at some future period, the bed of this inland sea should be converted into land, the geologist might be enabled, by reference to organic remains, to prove the contemporaneous origin of various mineral masses scattered over a space equal in area to half of Europe.

Deposits, for example, are well known to be now in progress in this sea in the deltas of the Po, Rhone, Nile, and other rivers, which differ as greatly from each other in the nature of their sediment as does the composition of the mountains which they drain. There are also other quarters of the Mediterranean, as off the coast of Campania, or near the base of Etna, in Sicily, or in the Grecian Archipelago, where another class of rocks is now forming; where showers of volcanic ashes occasionally fall into the sea, and streams of lava overflow its bottom; and where, in the intervals between volcanic eruptions, beds of sand and clay are frequently derived from the waste of cliffs, or the turbid waters of rivers. Limestones, moreover, such as the Italian travertins, are here and there precipitated from the waters of mineral springs, some of which rise up from the bottom of the sea. In all these detached formations, so diversified in their lithological characters, the remains of the same shells, corals, crustacea, and fish are becoming inclosed; or, at least, a sufficient number must be common to the different localities to enable the zoologist to refer them all to one contemporaneous assemblage of species.

There are, however, certain combinations of geographical circumstances which cause distinct provinces of animals and plants to be separated from each other by very narrow limits; and hence it must happen, that strata will be sometimes formed in contiguous regions, differing widely both in mineral contents and organic remains. Thus, for example, the testacea, zoophytes, and fish of the Red Sea are, as a group, extremely distinct from those inhabiting the adjoining parts of the Mediterranean, although the two seas are separated only by the narrow isthmus of Suez. Of the bivalve shells, according to Philippi, not more than a fifth are common to the Red Sea and the sea around Sicily, while the proportion of univalves (or Gasteropoda) is still smaller, not exceeding eighteen in a hundred. Calcareous formations have accumulated on a great scale in the Red Sea in modern times, and fossil shells of existing species are well preserved therein; and we know that at the mouth of the Nile large deposits of mud are amassed, including the remains of Mediterranean species. It follows, therefore, that if at some future period the bed of the Red Sea should be laid dry, the geologist might experience great difficulties in endeavouring to ascertain the relative age of these formations, which, although dissimilar both in organic and mineral characters, were of synchronous origin.

But, on the other hand, we must not forget that the north-western shores of the Arabian Gulf, the plains of Egypt, and the isthmus of Suez are all parts of one province of *terrestrial* species. Small streams, therefore, occasional land-floods, and those winds which drift clouds of sand along the deserts might carry down into the Red Sea the same shells of fluviatile and land testacea which the Nile is sweeping into its delta, together with some remains of terrestrial plants and the bones of quadrupeds, whereby the groups of strata, before alluded to, might, notwithstanding the discrepancy of their mineral composition and *marine* organic fossils, be shown to have belonged to the same epoch.

Yet while rivers may thus carry down the same fluviatile and terrestrial spoils into two or more seas inhabited by different marine species, it will much more frequently happen, that the co-existence of terrestrial species of distinct zoological and botanical provinces will be proved by the identity of the marine beings which inhabited the intervening space. Thus, for example, the land quadrupeds and shells of the south of Europe, north of Africa, and north-west of Asia differ considerably, yet their remains are all washed down by rivers flowing from these three countries into the Mediterranean.

In some parts of the globe, at the present period, the line of demarcation between distinct provinces of animals and plants is not very strongly marked, especially where the change is determined by temperature, as it is in seas extending from the temperate to the tropical zone, or from the temperate to the arctic regions. Here a gradual passage takes place from one set of species to another. In like manner the geologist, in studying particular formations of remote periods, has sometimes been able to trace the gradation from one ancient province to another, by observing carefully the fossils of all the intermediate places. His success in thus acquiring a knowledge of the zoological or botanical geography of very distant eras has been mainly owing to this circumstance, that the mineral character has no tendency to be affected by climate. A large river may convey yellow or red mud into some part of the ocean, where it may be dispersed by a current over an area several hundred leagues in length, so as to pass from the tropics into the temperate zone. If the bottom of the sea be afterwards upraised, the organic remains imbedded in such yellow or red strata may indicate the different animals or plants which once inhabited at the same time the temperate and equatorial regions.

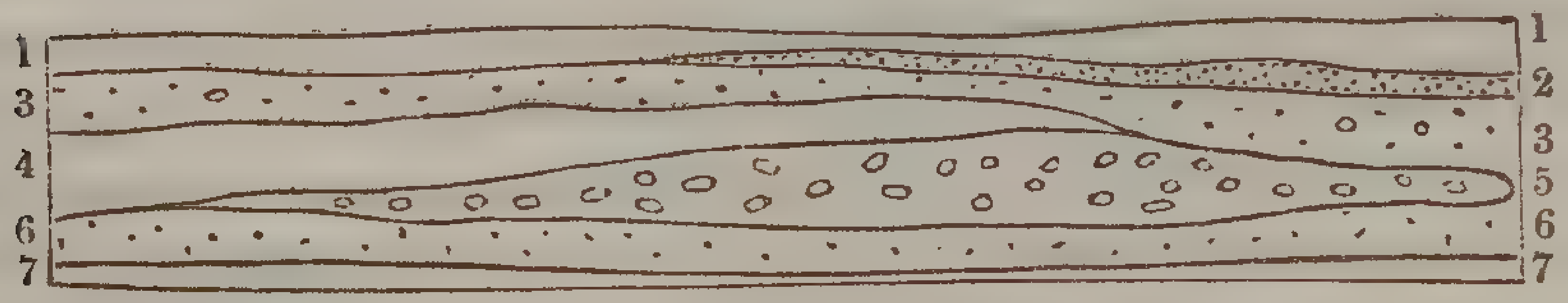
It may be true, as a general rule, that groups of the same species of animals and plants may extend over wider areas than deposits of homogeneous composition; and if so, palæontological characters will be of more importance in geological classification than the test of mineral composition; but it is idle to discuss the relative value of these tests, as the aid of both is indispensable, and it fortunately happens, that where the one criterion fails, we can often avail ourselves of the other.

Test by included fragments of older rocks.—It was stated, that independent proof may sometimes be obtained of the relative date of two formations, by fragments of an older rock being included in a newer one. This evidence may sometimes be of great use, where a geologist is at a loss to determine the relative age of two formations from want of clear sections exhibiting their true order of position, or because the strata of each group are vertical. In such cases we sometimes discover that the more modern rock has been in part derived from the degradation of the older. Thus, for example, we may find chalk with flints in one part of a country; and, in another, a distinct formation, consisting of alternations of clay, sand, and pebbles. If some of these pebbles consist of similar flint, including fossil shells, sponges, and foraminifera, of the same species as those in the chalk, we may confidently infer that the chalk is the oldest of the two formations.

Chronological groups.—The number of groups into which the fossiliferous strata may be separated are more or less numerous, according to the views of classification which different geologists entertain; but when we have adopted a certain system of arrangement, we immediately find that a few only of the entire series of groups occur one upon the other in any single section or district.

The thinning out of individual strata was before described (p. 16.).

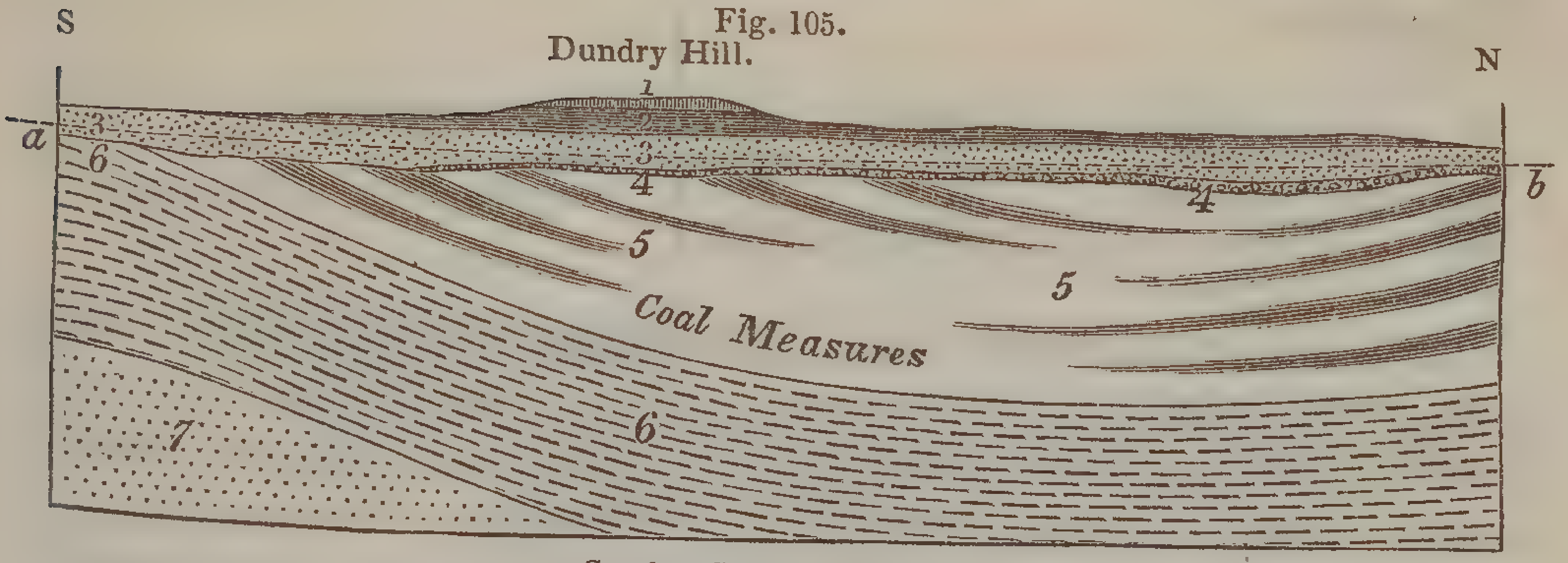
Fig. 104.



But let the annexed diagram represent seven fossiliferous groups, instead of as many strata. It will then be seen that in the middle all the superimposed formations are present; but in consequence of some of them thinning out, No. 2. and No. 5. are absent at one extremity of the section, and No. 4. at the other.

In another diagram, fig. 105., a real section of the geological formations in the neighbourhood of Bristol and the Mendip Hills is presented to the reader, as laid down on a true scale by Professor Ramsay, where the newer groups 1, 2, 3, 4. rest unconformably on the formations 5 and 6. Here at the southern end of the line of section we meet with the beds No. 3. (the New Red Sandstone) resting immediately on No. 6., while farther north, as at Dundry Hill, we behold six groups superimposed one upon the other, comprising all the strata from the inferior oolite to the coal and carboniferous limestone. The limited extension of the groups 1 and 2. is owing to denudation, as these formations end abruptly, and have left outlying patches to attest the fact of their having originally covered a much wider area.

Fig. 105.



Section South of Bristol. A. C. Ramsay.

Length of section 4 miles. *a, b.* Level of the sea.

1. Inferior oolite.
2. Lias.
3. New red sandstone.
4. Magnesian conglomerate.
5. Coal measure.
6. Carboniferous limestone.
7. Old red sandstone.

In many instances, however, the entire absence of one or more formations of intervening periods between two groups, such as 3. and 5. in the same section, arises, not from the destruction of what once existed, but because no strata of an intermediate age were ever deposited on the inferior rock. They were not formed at that place, either because the region was dry land during the interval, or because it was part of a sea or lake to which no sediment was carried.

In order, therefore, to establish a chronological succession of fossiliferous groups, a geologist must begin with a single section in which several sets of strata lie one upon the other. He must then trace these formations, by attention to their mineral character and fossils, continuously, as far as possible, from the starting point. As often as he meets with new groups, he must ascertain by superposition their age relatively to those first examined, and thus learn how to intercalate them in a tabular arrangement of the whole.

By this means the German, French, and English geologists have determined the succession of strata throughout a great part of Europe, and have adopted pretty generally the following groups, almost all of which have their representatives in the British Islands.

Groups of Fossiliferous Strata observed in Western Europe, arranged in what is termed a descending Series, or beginning with the newest. (*See a more detailed Tabular view*, pp. 104. 109.)

1. Post-Pliocene, including those of the Recent, or Human period.	
2. Newer Pliocene, or Pleistocene.	Tertiary, Supracretaceous *, or Cainozoic.†
3. Older Pliocene.	
4. Miocene.	
5. Eocene.	
6. Chalk.	Secondary, or Mesozoic.
7. Greensand and Wealden.	
8. Upper Oolite, including the Purbeck.	
9. Middle Oolite.	
10. Lower Oolite.	
11. Lias.	
12. Trias.	

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* For tertiary, Sir H. De La Beche has used the term "supracretaceous," a name implying that the strata so called are superior in position to the chalk.

† For an explanation of Cainozoic &c. see above, p. 95.

13. Permian.	Primary fossiliferous, or palæozoic.
14. Coal.	
15. Old Red sandstone, or Devonian.	
16. Upper Silurian.	
17. Lower Silurian.	
18. Cambrian and older fossiliferous strata.	

It is not pretended that the three principal sections in the above table, called primary, secondary, and tertiary, are of equivalent importance, or that the eighteen subordinate groups comprise monuments relating to equal portions of past time, or of the earth's history. But we can assert that they each relate to successive periods, during which certain animals and plants, for the most part peculiar to their respective eras, have flourished, and during which different kinds of sediment were deposited in the space now occupied by Europe.

If we were disposed, on palæontological grounds*, to divide the entire fossiliferous series into a few groups less numerous than those in the above table, and more nearly co-ordinate in value than the sections called primary, secondary, and tertiary, we might, perhaps, adopt the six groups or periods given in the next table.

At the same time, I may observe, that, in the present state of the science, when we have not yet compared the evidence derivable from all classes of fossils, not even those most generally distributed, such as shells, corals, and fish, such generalizations are premature, and can only be regarded as conjectural or provisional schemes for the founding of large natural groups.

Fossiliferous Strata of Western Europe divided into Six Groups.

1. Post-Pliocene and Tertiary - -	from the Post-Pliocene to the Eocene inclusive.
2. Cretaceous - -	from the Maestricht Chalk to the Wealden inclusive.
3. Oolitic - - -	from the Purbeck to the Lias inclusive.
4. Triassic - -	including the Keuper, Muschelkalk, and Bunter-Sandstein of the Germans.
5. Permian, Carboniferous, and Devonian	including Magnesian Limestone (Zechstein), Coal, Mountain Limestone, and Old Red Sandstone.
6. Silurian and Cambrian - - -	from the Upper Silurian to the oldest fossiliferous rocks inclusive.

But the following more detailed list of fossiliferous strata, divided into thirty-three sections, will be required by the reader when he is studying our descriptions of the sedimentary formations given in the next 18 chapters.

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* Palæontology is the science which treats of fossil remains, both animal and vegetable. *Etym.* παλαιος, *palaios*, ancient, οντα, *onta*, beings, and λογος, *logos*, a discourse.

TABULAR VIEW
OF THE
FOSSILIFEROUS STRATA,

Showing the Order of Superposition or Chronological Succession of the principal Groups.

Periods and Groups.	British Examples.	Foreign Equivalents and Synonyms.
I. POST-TERTIARY.		I. Terrains Contemporaines, et quaternaires.
A. POST-PLIOCENE.		
1. RECENT.	Peat of Great Britain and Ireland, with human remains. (Principles of Geology, ch. 45.) Alluvial plains of the Thames, Mersey, and Rother, with buried ships, p. 120., and Principles, ch. 48.	Part of the Terrain quaternaire of French authors. Modern part of deltas of Rhine, Nile, Ganges, Mississippi, &c. Modern part of coral-reefs of Red Sea and Pacific. Marine strata inclosing Temple of Serapis at Puzzuoli. Principles, ch. 29. Freshwater strata inclosing Temple in Cashmere. *Ibid.* 9th ed. p. 762.
2. POST-PLIOCENE.	Ancient raised beach of Brighton. *b*, fig. 331., p. 288. Alluvium, gravel, brick-earth, &c. with fossil shells of living species, but sometimes locally extinct, and with bones of land animals, partly of extinct species; no human remains.	Part of Terrain quaternaire of French authors. Volcanic tuff of Ischia, with living species of marine shells and without human remains or works of art, p. 118. Loess of the Rhine, with recent freshwater shells, and mammoth bones, p. 122. Newer part of boulder-formation in Sweden, p. 130. Bluffs of Mississippi, p. 122.
II. TERTIARY.		II. Terrains Tertiaires.
B. PLIOCENE.		
3. **NEWER PLIOCENE, or Pleistocene.**	Glacial drift or boulder-formation of Norfolk, p. 132., of the Clyde in Scotland, p. 131., of North Wales, p. 137. Norwich Crag, p. 155.—Cave-deposits of Kirkdale, &c. with bones of extinct and living quadrupeds, p. 161.	Terrain quaternaire, diluvium. Terrains tertiaires supérieurs, p. 139. Glacial drift of Northern Europe, p. 129.; and of Northern United States, p. 140.; and Alpine erratics, p. 149. Limestone of Girgenti, p. 159. Australian cave-breccias, p. 162.
4. **OLDER PLIOCENE.**	Red Crag of Suffolk, pp. 169—171. Coralline crag of Suffolk, pp. 169—172.	Subapennine strata, p. 174. Hills of Rome, Monte Mario, &c. p. 176. and p. 535. Antwerp and Normandy crag, p. 174. Aralo-Caspian deposits, p. 176.
C. MIOCENE.		*C.* Terrains Tertiaires moyens, partie supérieure; or faluns.
5. **MIOCENE.**	Marine strata of this age wanting in the British Isles. Leaf-bed of Mull in the Hebrides? p. 180. Lignite of Antrim?, p. 181.	Falurien supérieur, D'Orbigny. Faluns of Touraine, p. 176. Part of Bourdeaux beds, p. 179. Bolderberg strata in Belgium, p. 179. Part of Vienna basin, p. 180. Part of Molasse, Switzerland, p. 180. Sands of James River, and Richmond, Virginia, United States, p. 182.

Periods and Groups.	British Examples.	Foreign Equivalents and Synonyms.
D. EOCENE.		
6. UPPER EOCENE (Lower Miocene of many authors).	Hempstead beds, near Yarmouth, Isle of Wight, p. 193.	Lower part of Terrain Tertiaire Moyen. Calcaire Lacustre Supérieur and Grès de Fontainbleau, p. 195. Part of the Lacustrine strata of Auvergne, p. 195. Kleyn Spawen or Limburg beds, Belgium—Rupelian and Tongrian systems of Dumont, p. 189. Mayence basin, p. 191. Part of brown-coal of Germany, pp. 192. 544. Hermsdorf tile-clay near Berlin, p. 190.
7. MIDDLE EOCENE.	1. Bembridge, or Binstead Beds, Isle of Wight, p. 209. 2. Osborne or St. Helen's Series, p. 211. 3. Headon Series. *Ibid.* 4. Headon Hill Sands, and Barton Clay, p. 213. 5. Bagshot and Bracklesham Beds, p. 214. 6. Wanting? See p. 223.	1. Gypseous Series of Montmartre, and Calcaire lacustre supérieur, p. 224. 2 & 3. Calcaire Siliceux, p. 226. 2 & 3. Grès de Beauchamp, or Sables Moyens, p. 227. Laecken beds, Belgium. 4 & 5. Upper and Middle Calcaire Grossier, p. 227. 5. Bruxellien, or Brussels beds of Dumont. 5. Lower Calcaire Grossier, or Glauconie Grossière, p. 229. 5. Claiborne beds, Alabama, United States, p. 233. 5 & 6. Nummulitic formation of Europe, Asia, &c., p. 230. 6. Soissonnais Sands, or Lits Coquilliers, p. 229.
8. LOWER EOCENE.	1. London Clay and Bognor Beds, p. 217. 2. Plastic and Mottled Clays and Sands, and Wolwich Beds, p. 220. 3. Thanet Sands, p. 222.	1. Wanting in Paris basin, occurs at Cassel, in French Flanders. 2. Argile Plastique et Lignite, p. 230. 3. Lower Landenian of Belgium, in part?, p. 236.
III. SECONDARY.		III. Terrains Secondaires.
E. CRETACEOUS.		*E.* Terrains Cretacées.
§ Upper Cretaceous.		
9. MAESTRICHT BEDS.	Wanting in England.	9. Danien of D'Orbigny. Calcaire pisolitique, near Paris, p. 236. Maestricht Beds, p. 238. Coralline Limestone of Faxoe in Denmark, p. 239.
10. UPPER WHITE CHALK.	White Chalk with Flints, of North and South Downs, p. 240.	10. Senonien, D'Orbigny. Craie blanche avec silex. Obere Kreide of the Germans. Upper Quadersandstein? of the same. La Scaglia of the Italians.
11. LOWER WHITE CHALK.	Chalk without Flints, and Chalk Marl, p. 240. Chalk Marl. *Ibid.*	Calcaire à hippurites, Pyrennees. Turonien, D'Orb., or, Craie tufeau of Touraine. Craie argileuse of some French writers. Upper Plänerkalk of Saxony.
12. UPPER GREENSAND.	Loose sand with bright green grains, p. 251. Firestone of Merstham, Surrey, *ibid.* Marly Stone with Chert, Isle of Wight.	Grès vert supérieur. Glauconie crayeuse. Craie chloritée. Cenomanien, D'Orbigny. Lower Quadersandstein of the Germans.
13. GAULT.	Dark Blue Marl, Kent, p. 251. Folkestone Marl or Clay. Blackdown Beds, green sand and chert, Devonshire, p. 252.	Grès vert supérieur Glauconie crayeuse } in part. Albien, D'Orbigny. Lower Pläner of Saxony.
§§ Lower Cretaceous, or Neocomian.		
14. LOWER GREENSAND.	Sand with green matter, Weald of Kent and Sussex, p. 258. Limestone (Kentish Rag,) p. 258. Sands and clay with calcareous concretions and chert. Atherfield, Isle of Wight, p. 258. Speeton Clay, Yorkshire.	Grès vert inférieur. Néocomien supérieur. Aptien, D'Orbigny. Hils-conglomerat of Germany. Hils-thon of Brunswick.

Periods and Groups.	British Examples.	Foreign Equivalents and Synonyms.
15. **WEALDEN** **(Weald Clay and Hastings Sand).**	Clay with occasional bands of limestone.—Weald of Kent, Surrey, and Sussex, p. 261. Sand with calcareous grit and clay, — Hastings, Cuckfield, Sussex, p. 263.	Formation Waldienne. Neocomien inférieur.
F. OOLITE.		*F.* TERRAINS JURASSIQUES, in part.
§ UPPER OOLITE.		
16. **PURBECK BEDS.**	Upper, Middle, and Lower Purbeck, Dorsetshire and Wilts, pp. 294—297.	Serpulitenkalk of Dunker, and associated beds of the North German Wälderformation.
17. **PORTLAND BEDS.**	Portland stone and Portland sand, p. 301.	Groupe Portlandien of Beudant.
18. **KIMMERIDGE CLAY.**	Clay of Kimmeridge, Dorsetshire, p. 301.	Kimmeridgien, D'Orbigny. Calcaire à gryphées virgules, of Thirria. Argiles de Honfleur, E. de Beaumont et Dufresnoy.
§§ MIDDLE OOLITE.		
19. **CORAL-RAG.**	Calcareous grit. Coral-rag or oolitic limestone with corals, Oxfordshire, p. 303.	Groupe corallien of Beudant. Corallien, D'Orbigny. Calcaire à Nérinnées of Thurmann and Thirria.
20. **OXFORD CLAY.**	1. Dark blue clay, Oxfordshire and Midland counties, p. 305. 2. Calcareous concretionary limestone with shells, called Kelloway Rock, p. 34.	1. Oxfordien supérieur, Thurmann. 2. Oxfordien inférieur, or Callovien, D'Orbigny.
§§§ LOWER OOLITE.		
21. **GREAT or BATH OOLITE.**	1. Cornbrash and Forest Marble, Wiltshire, p. 306. 2. Great Oolite and Stonesfield Slate,—Bath, Stonesfield, pp. 306. 310.	Bathonien of Omalius D'Halloy. Grand Oolithe. Calcaire de Caen.
22. **INFERIOR OOLITE.**	Fuller's Earth, near Bath, p. 315. Calcareous freestone, and yellow sands of Cotteswold Hills, Gloucestershire, p. 315. Dundry Hill, near Bristol, pp. 103. 315.	Oolithe inférieur. Oolithe ferrugineux of Normandy. Oolithe de Bayeux. Bajocien of D'Orbigny.
G. LIAS.		*G.* TERRAINS JURASSIQUES, in part.
23. **LIAS.**	1. Upper Lias, p. 319. 2. Marl-stone, *ibid.* 3. Lower Lias, *ibid.*	1. Étage supérieur du Lias, Thirria. Toarcien, D'Orbigny. 2. Lias moyen. Liasien, D'Orbigny. 3. Calcaire à gryphée arquée. Sinémurien, D'Orbigny. Coal-field near Richmond, Virginia, p. 331.
H. TRIAS. (*Upper New Red Sandstone*).		*H.* NOUVEAU GRÈS ROUGE.
24. **UPPER TRIAS.**	Saliferous and Gypseous sandstones and shales of Cheshire, pp. 335—338. Bone-bed of Axmouth, Devon, p. 338.	Keuper of the Germans. Marnes irisées of the French. Salifèrien, D'Orbigny.
25. **MIDDLE TRIAS or Muschelkalk.**	Wanting in England.	Muschelkalk of the Germans. Calcaire conchylien, Brongniart. Calcaire à Cératites, Cordier. Conchylien, D'Orbigny, (in part).
26. **LOWER TRIAS**	Red and white Sandstone of Lancashire and Cheshire pp. 338, 339.	Bunter-Sandstein of the Germans. Grès bigarré of the French. Conchylien, D'Orbigny, (in part).

Periods and Groups.	British Examples.	Foreign Equivalents and Synonyms.
IV. PRIMARY.		IV. Terrains de transition. Terrains Paléozoiques.
I. PERMIAN, or Magnesian Limestone. (*Lower New Red.*)		*I.* Calcaire Magnesien.
27. PERMIAN, or MAGNESIAN LIMESTONE.	1. Concretionary limestone of Durham and Yorkshire, p. 354. 2. Brecciated limestone, *ibid.* 3. Fossiliferous limestone, p. 355. 4. Compact limestone, *ibid.* 5. Marl-slate of Durham, p. 356. 6. Inferior sandstones of various colours,—N. of England, p. 357. Dolomitic conglomerate,—Bristol, p. 357.	1. Stinkstein of Thuringia. 2. Rauchwacke, *ibid.* 3. Dolomit or Upper Zechstein. 4. Zechstein, p. 353. 5. Mergel or Kupfer-schiefer. 6. Rothliegendes of Thuringia. Permian of Russia, p. 358. Grès des Vosges of French, (in part).
K. CARBONIFEROUS.		*K.* Terrain houillier.
28. UPPER CARBONIFEROUS.	1. Coal-measures, sandstone and shale with seams of coal,—West of England and Ireland, Chapters 24 and 25. 2. Millstone Grit, pp. 361, 362.	Coal-fields of the United States, p. 391.
29. LOWER CARBONIFEROUS.	1. Mountain or Carboniferous limestone, p. 407. *et seq.* 2. Lower limestone shale,—Mendips. Carboniferous slate,—Ireland. Carbonaceous schist with Possidonomya Becheri, p. 413.	1. Calcaire carbonifère of the French. 1. Bergkalk or Kohlenkalk of the Germans. 1. Pentremite limestone, United States, p. 414. Kiesel-schiefer and Jüngere Grauwacke of the Germans, p. 413. Gypseous beds and Encrinital limestone of Nova Scotia, p. 413.
L. DEVONIAN, or Old Red Sandstone.		*L.* Terrain devonien. Vieux grès rouge.
30. UPPER DEVONIAN.	Yellow sandstone of Dura Den, Fife, p. 416. White sandstone of Elgin, with Telerpeton, *ibid.* Red sandstone and conglomerate, p. 418. Upper and middle Devonian of N. Devon, including Plymouth limestone, pp. 424. 426.	Russian Devonian, Upper part, p. 429. Catskill group, United States, p. 430. Eifel Limestone, p. 428. Limestone of Villmar, &c., Nassau.
31. LOWER DEVONIAN.	Lower Devonian of N. Devon, North Foreland, p. 428. Arbroath paving-stone, pp. 416—419. Bituminous schists of Caithness, p. 422.	1. Spirifer Sandstone and Slate of Sandberger, p. 428. Older Rhenish Greywacke of Roemer, *ibid.* Russian Devonian, Lower part, p. 429.
M. SILURIAN.		*M.* Terrain Silurien.
32. UPPER SILURIAN.	1. Upper Ludlow, p. 434. 2. Aymestry Limestone, p. 438. 3. Lower Ludlow, *ibid.* 4. Wenlock Limestone, p. 439. 5. Wenlock shale, p. 441.	New York division from the Upper Pentamerus to the Niagara Group inclusive, p. 448. Étages E. to H. of Barrande, Bohemia.
32 *a.* Middle Silurian. (*Beds of passage between Upper and Lower Silurian*).	Caradoc or May Hill Sandstone, p. 441.	New York groups from the Clinton to the Grey sandstone inclusive, p. 448.
33. LOWER SILURIAN.	Llandeilo Flags and shale, p. 443. Bala Limestone and black slate, p. 445. Graptolite Schists, S. of Scotland. Limestone, Chair of Kildare, Ireland.	New York groups from the Hudson-River beds to the Calciferous sandstone inclusive, p. 448. Étages C. and D. (Barrande), Bohemia. Slates of Angers, France.
N. CAMBRIAN.		
34. UPPER CAMBRIAN.	Lingula Flags, North Wales, p. 452. Stiper Stones, Shropshire.	Primordial zone of Barrande in Bohemia, p. 454. Alum Schists of Sweden, p. 455. Potsdam Sandstone of United States and Canada, p. 455. Wisconsin and Minnesota, lowest fossiliferous rocks, p. 456.
35. LOWER CAMBRIAN.	Lowest fossiliferous rocks of Wicklow in Ireland, p. 453.	

ABRIDGED TABLE OF FOSSILIFEROUS STRATA.

1. RECENT.		**POST-TERTIARY.**		
2. POST-PLIOCENE.				
3. NEWER PLIOCENE.		**PLIOCENE.**	TERTIARY or CAINOZOIC.	NEOZOIC.
4. OLDER PLIOCENE.				
5. MIOCENE.		**MIOCENE.**		
6. UPPER EOCENE.		**EOCENE.**		
7. MIDDLE EOCENE.				
8. LOWER EOCENE.				
9. MAESTRICHT BEDS.		**CRETACEOUS.**	SECONDARY or MESOZOIC.	
10. UPPER WHITE CHALK.				
11. LOWER WHITE CHALK.				
12. UPPER GREENSAND.				
13. GAULT.				
14. LOWER GREENSAND.				
15. WEALDEN.				
16. PURBECK BEDS.		**JURASSIC.**		
17. PORTLAND STONE.				
18. KIMMERIDGE CLAY.				
19. CORAL RAG.				
20. OXFORD CLAY.				
21. GREAT or BATH OOLITE.				
22. INFERIOR OOLITE.				
23. LIAS.				
24. UPPER TRIAS.		**TRIASSIC.**		
25. MIDDLE TRIAS, or MUSCHELKALK.				
26. LOWER TRIAS.				
27. PERMIAN, or MAGNESIAN LIMESTONE.		**PERMIAN.**	PRIMARY or PALEOZOIC.	PALEOZOIC.
28. COAL-MEASURES.		**CARBONIFEROUS.**		
29. CARBONIFEROUS LIMESTONE.				
30. UPPER	DEVONIAN.	**DEVONIAN.**		
31. LOWER				
32. UPPER	SILURIAN.	**SILURIAN.**		
33. LOWER				
34. UPPER	CAMBRIAN.	**CAMBRIAN.**		
35. LOWER				

CHAPTER X.

CLASSIFICATION OF TERTIARY FORMATIONS.—POST-PLIOCENE GROUP.

General principles of classification of tertiary strata—Detached formations scattered over Europe—Strata of Paris and London—More modern groups—Peculiar difficulties in determining the chronology of tertiary formations—Increasing proportion of living species of shells in strata of newer origin—Terms Eocene, Miocene, and Pliocene—Post-Pliocene strata—Recent or human period—Older Post-Pliocene formations of Naples, Uddevalla, and Norway—Ancient upraised delta of the Mississippi—Loess of the Rhine.

BEFORE describing the most modern of the sets of strata enumerated in the Tables given at the end of the last chapter, it will be necessary to say something generally of the mode of classifying the formations called tertiary.

The name of tertiary has been given to them, because they are all posterior in date to the rocks termed "secondary," of which the chalk constitutes the newest group. These tertiary strata were at first confounded, as before stated, p. 91., with the superficial alluviums of Europe; and it was long before their real extent and thickness, and the various ages to which they belong, were fully recognized. They were observed to occur in patches, some of freshwater, others of marine origin, their geographical area being usually small as compared to the secondary formations, and their position often suggesting the idea of their having been deposited in different bays, lakes, estuaries, or inland seas, after a large portion of the space now occupied by Europe had already been converted into dry land.

The first deposits of this class, of which the characters were accurately determined, were those occurring in the neighbourhood of Paris, described in 1810 by MM. Cuvier and Brongniart. They were ascertained to consist of successive sets of strata, some of marine, others of freshwater origin, lying one upon the other. The fossil shells and corals were perceived to be almost all of unknown species, and to have in general a near affinity to those now inhabiting warmer seas. The bones and skeletons of land animals, some of them of large size, and belonging to more than forty distinct species, were examined by Cuvier, and declared by him not to agree specifically, nor even for the most part generically, with any hitherto observed in the living creation.

Strata were soon afterwards brought to light in the vicinity of London, and in Hampshire, which, although dissimilar in mineral composition, were justly inferred by Mr. T. Webster to be of the same age as those of Paris, because the greater number of the fossil shells were specifically identical. For the same reason, rocks found on the Gironde, in the South of France, and at certain points in the North of Italy, were suspected to be of contemporaneous origin.

A variety of deposits were afterwards found in other parts of Europe, all reposing immediately on rocks as old or older than the chalk, and which exhibited certain general characters of resemblance in their organic remains to those previously observed near Paris and London. An attempt was therefore made at first to refer the whole to one period; and when at length this seemed impracticable, it was contended that as in the Parisian series there were many subordinate formations of considerable thickness which must have accumulated one after the other, during a great lapse of time, so the various patches of tertiary strata scattered over Europe might correspond in age, some of them to the older, and others to the newer, subdivisions of the Parisian series.

This error, though almost unavoidable on the part of those who made the first generalizations in this branch of geology, retarded seriously for some years the progress of classification. A more scrupulous attention to specific distinctions, aided by a careful regard to the relative position of the strata containing them, led at length to the conviction that there were formations both marine and freshwater of various ages, and all newer than the strata of the neighbourhood of Paris and London.

One of the first steps in this chronological reform was made in 1811, by an English naturalist, Mr. Parkinson, who pointed out the fact that certain shelly strata, provincially termed "Crag" in Suffolk, lie decidedly over a deposit which was the continuation of the blue clay of London. At the same time he remarked that the fossil testacea in these newer beds were distinct from those of the blue clay, and that while some of them were of unknown species, others were identical with species now inhabiting the British seas.

Another important discovery was soon afterwards made by Brocchi in Italy, who investigated the argillaceous and sandy deposits, replete with shells, which form a low range of hills, flanking the Apennines on both sides, from the plains of the Po to Calabria. These lower hills were called by him the Subapennines, and were formed of strata chiefly marine, and newer than those of Paris and London.

Another tertiary group occurring in the neighbourhood of Bordeaux and Dax, in the south of France, was examined by M. de Basterot in 1825, who described and figured several hundred species of shells, which differed for the most part both from the Parisian series and those of the Subapennine hills. It was soon, therefore, suspected that this fauna might belong to a period intermediate between that of the Parisian and Subapennine strata, and it was not long before the evidence of superposition was brought to bear in support of this opinion; for other strata, contemporaneous with those of Bordeaux, were observed in one district (the Valley of the Loire), to overlie the Parisian formation, and in another (in Piedmont) to underlie the Subapennine beds. The first example of these was pointed out in 1829 by M. Desnoyers, who ascertained that the sand and marl of marine origin called Faluns, near Tours, in the basin of the Loire, full of sea-shells and corals, rested upon a lacustrine formation, which constitutes the uppermost subdivision of the Parisian group, extending continuously throughout a great table-land intervening between the basin of the Seine and that of the Loire. The other example occurs in Italy, where strata, containing many fossils similar to those of Bordeaux, were observed by Bonelli and others in the environs of Turin, subjacent to strata belonging to the Subapennine group of Brocchi.

Without pretending to give a complete sketch of the progress of discovery, I may refer to the facts above enumerated, as illustrating the course usually pursued by geologists when they attempt to found new chronological divisions. The method bears some analogy to that pursued by the naturalist in the construction of genera, when he selects a typical species, and then classes as congeners all other species of animals and plants which agree with this standard within certain limits. The genera A. and C. having been founded on these principles, a new species is afterwards met with, departing widely both from A. and C., but in many respects of an intermediate character. For this new type it becomes necessary to institute the new genus B., in which are included all species afterwards brought to light, which agree more nearly with B. than with the types of A. or C. In like manner a new formation is met with in geology, and the characters of its fossil fauna and flora investigated. From that moment it is considered as a record of a certain period of the earth's history, and a standard to which other deposits may be compared. If any are found containing the same or nearly the same organic remains, and occupying the same relative position, they are regarded in the light of contemporary annals. All such monuments are said to relate to one period, during which certain events occurred, such as the formation of particular rocks by aqueous or volcanic agency, or the continued existence and fossilization of certain tribes of animals and plants. When several of these periods have had their true places assigned to them in a chronological series, others are discovered which it becomes necessary to intercalate between those first known ; and the difficulty of assigning clear lines of separation must unavoidably increase in proportion as chasms in the past history of the globe are filled up.

Every zoologist and botanist is aware that it is a comparatively easy task to establish genera in departments which have been enriched with only a small number of species, and where there is as yet no tendency in one set of characters to pass almost insensibly, by a multitude of connecting links, into another. They also know that the difficulty of classification augments, and that the artificial nature of their divisions becomes more apparent, in proportion to the increased number of objects brought to light. But in separating families and genera, they have no other alternative than to avail themselves of such breaks as still remain, or of every hiatus in the chain of animated beings which is not yet filled up. So in geology, we may be eventually compelled to resort to sections of time as arbitrary, and as purely conventional, as those which divide the history of human events into centuries. But in the present state of our knowledge, it is more convenient to use the interruptions which still occur in the regular sequence of geological monuments, as boundary lines between our principal groups or periods, even though the groups thus established are of very unequal value.

The isolated position of distinct tertiary deposits in different parts of Europe has been already alluded to. In addition to the difficulty presented by this want of continuity when we endeavour to settle the chronological relations of these deposits, another arises from the frequent dissimilarity in mineral character of strata of contemporaneous date, such, for example, as those of London and Paris before mentioned. The identity or non-identity of species is also a criterion which often fails us. For this we might have been prepared, for we have already seen, that the Mediterranean and Red Sea, although within 70 miles of each other, on each side of the Isthmus of Suez, have each their peculiar fauna; and a marked difference is found in the four groups of testacea now living in the Baltic, English Channel, Black Sea, and Mediterranean, although all these seas have many species in common. In like manner a considerable diversity in the fossils of different tertiary formations, which have been thrown down in distinct seas, estuaries, bays, and lakes, does not always imply a distinctness in the times when they were produced, but may have arisen from climate and conditions of physical geography wholly independent of time. On the other hand, it is now abundantly clear, as the result of geological investigation, that different sets of tertiary strata, immediately superimposed upon each other, contain distinct imbedded species of fossils, in consequence of fluctuations which have been going on in the animate creation, and by which in the course of ages one state of things in the organic world has been substituted for another wholly dissimilar. It has also been shown that in proportion as the age of a tertiary deposit is more modern, so is its fauna more analogous to that now in being in the neighbouring seas. It is this law of a nearer agreement of the fossil testacea with the species now living, which may often furnish us with a clue for the chronological arrangement of scattered deposits, where we cannot avail ourselves of any one of the three ordinary chronological tests; namely, superposition, mineral character, and the specific identity of the fossils.

Thus, for example, on the African border of the Red Sea, at the height of 40 feet, and sometimes more, above its level, a white calcareous formation has been observed, containing several hundred species of shells differing from those found in the clay and volcanic tuff of the country round Naples, and of the contiguous island of Ischia. Another deposit has been found at Uddevalla, in Sweden, in which the shells do not agree with those found near Naples. But although in these three cases there may be scarcely a single shell common to the three different deposits, we do not hesitate to refer them all to one period (the Post-Pliocene), because of the very close agreement of the fossil species in every instance with those now living in the contiguous seas.

To take another example, where the fossil fauna recedes a few steps farther back from our own times. We may compare, first, the beds of loam and clay bordering the Clyde in Scotland (called glacial by some geologists); secondly, others of fluvio-marine origin near Norwich; and, lastly, a third set often rising to considerable heights in Sicily: and we discover that in every case more than three-fourths of the shells agree with species still living, while the remainder are extinct. Hence we may conclude that all these, greatly diversified as are their organic remains, belong to one and the same era, or to a period immediately antecedent to the Post-Pliocene, because there has been time in each of the areas alluded to for an equal or nearly equal amount of change in the marine testaceous fauna. Contemporaneousness of origin is inferred in these cases, in spite of the most marked differences of mineral character or organic contents, from a similar degree of divergence in the shells from those now living in the adjoining seas. The advantage of such a test consists in supplying us with a common point of departure in all countries, however remote.

But the farther we recede from the present times, and the smaller the relative number of recent as compared with extinct species in the tertiary deposits, the less confidence can we place in the exact value of such a test, especially when comparing the strata of very distant regions; for we cannot presume that the rate of former alterations in the animate world, or the continual going out and coming in of species, has been every where exactly equal in equal quantities of time. The form of the land and sea, and the climate, may have changed more in one region than in another; and consequently there may have been a more rapid destruction and renovation of species in one part of the globe than elsewhere. Considerations of this kind should undoubtedly put us on our guard against relying too implicitly on the accuracy of this test; yet it can never fail to throw great light on the chronological relations of tertiary groups with each other, and with the Post-Pliocene period.

We may derive a conviction of this truth not only from a study of geological monuments of all ages, but also by reflecting on the tendency which prevails in the present state of nature to a uniform rate of simultaneous fluctuation in the flora and fauna of the whole globe. The grounds of such a doctrine cannot be discussed here, and I have explained them at some length in the third Book of the Principles of Geology, where the causes of the successive extinction of species are considered. It will be there seen that each local change in climate and physical geography is attended with the immediate increase of certain species, and the limitation of the range of others. A revolution thus effected is rarely, if ever, confined to a limited space, or to one geographical province of animals or plants, but affects several other surrounding and contiguous provinces. In each of these, moreover, analogous alterations of the stations and habitations of species are simultaneously in progress, reacting in the manner already alluded to on the first province. Hence, long before the geography of any particular district can be essentially altered, the flora and fauna throughout the world will have been materially modified by countless disturbances in the mutual relation of the various members of the organic creation to each other. To assume that in one large area inhabited exclusively by a single assemblage of species any important revolution in physical geography can be brought about, while other areas remain stationary in regard to the position of land and sea, the height of mountains, and so forth, is a most improbable hypothesis, wholly opposed to what we know of the laws now governing the aqueous and igneous causes. On the other hand, even were this conceivable, the communication of heat and cold between different parts of the atmosphere and ocean is so free and rapid, that the temperature of certain zones cannot be materially raised or lowered without others being immediately affected; and the elevation or diminution in height of an important chain of mountains or the submergence of a wide tract of land would modify the climate even of the antipodes.

It will be observed that in the foregoing allusions to organic remains, the testacea or the shell-bearing mollusca are selected as the most useful and convenient class for the purposes of general classification. In the first place, they are more universally distributed through strata of every age than any other organic bodies. Those families of fossils which are of rare and casual occurrence are absolutely of no avail in establishing a chronological arrangement. If we have plants alone in one group of strata and the bones of mammalia in another, we can draw no conclusion respecting the affinity or discordance of the organic beings of the two epochs compared; and the same may be said if we have plants and vertebrated animals in one series and only shells in another. Although corals are more abundant, in a fossil state, than plants, reptiles, or fish, they are still rare when contrasted with shells, especially in the European tertiary formations. The utility of the testacea is, moreover, enhanced by the circumstance that some forms are proper to the sea, others to the land, and others to freshwater. Rivers scarcely ever fail to carry down into their deltas some land shells, together with species which are at once fluviatile and lacustrine. By this means we learn what terrestrial, freshwater, and marine species co-existed at particular eras of the past: and having thus identified strata formed in seas with others which originated contemporaneously in inland lakes, we are then enabled to advance a step farther, and show that certain quadrupeds or aquatic plants, found fossil in lacustrine formations, inhabited the globe at the same period when certain fish, reptiles, and zoophytes lived in the ocean.

Among other characters of the molluscous animals, which render them extremely valuable in settling chronological questions in geology, may be mentioned, first, the wide geographical range of many species; and, secondly, what is probably a consequence of the former, the great duration of species in this class, for they appear to have surpassed in longevity the greater number of the mammalia and fish. Had each species inhabited a very limited space, it could never, when imbedded in strata, have enabled the geologist to identify deposits at distant points; or had they each lasted but for a brief period, they could have thrown no light on the connection of rocks placed far from each other in the chronological, or, as it is often termed, vertical series.

Many authors have divided the European tertiary strata into three groups — lower, middle, and upper; the lower comprising the oldest formations of Paris and London before mentioned; the middle those of Bordeaux and Touraine; and the upper all those newer than the middle group.

When engaged in 1828 in preparing my work on the Principles of Geology, I conceived the idea of classing the whole series of tertiary strata in four groups, and endeavouring to find characters for each, expressive of their different degrees of affinity to the living fauna. With this view, I obtained information respecting the specific identity of many tertiary and recent shells from several Italian naturalists, and among others from Professors Bonelli, Guidotti, and Costa. Having in 1829 become acquainted with M. Deshayes, of Paris, already well known by his conchological works, I learnt from him that he had arrived, by independent researches, and by the study of a large collection of fossil and recent shells, at very similar views respecting the arrangement of tertiary formations. At my request he drew up, in a tabular form, lists of all the shells known to him to occur both in some tertiary formation and in a living state, for the express purpose of ascertaining the proportional number of fossil species identical with the recent which characterized successive groups; and this table, planned by us in common, was published by me in 1833.* The number of tertiary fossil shells examined by M. Deshayes was about 3000; and the recent species with which they had been compared about 5000. The result then arrived at was, that in the lower tertiary strata, or those of London and Paris, there were about 3½ per cent. of species identical with recent; in the middle tertiary of the Loire and Gironde about 17 per cent.; and in the upper tertiary or Subapennine beds, from 35 to 50 per cent. In formations still more modern, some of which I had particularly studied in Sicily, where they attain a vast thickness and elevation above the sea, the number of species identical with those now living was believed to be from 90 to 95 per cent. For the sake of clearness and brevity, I proposed to give short technical names to these four groups, or the periods to which they respectively belonged. I called the first or oldest of them Eocene, the second Miocene, the third Older Pliocene, and the last or fourth Newer Pliocene. The first of the above terms, Eocene, is derived from ηως, eos, *dawn*, and καινος, cainos, *recent*, because the fossil shells of this period contain an extremely small proportion of living species, which may be looked upon as indicating the dawn of the existing state of the testaceous fauna, no recent species having been detected in the older or secondary rocks.

The term Miocene (from μειον, meion, *less*, and καινος, cainos, *recent*) is intended to express a minor proportion of recent species (of testacea), the term Pliocene (from πλειον, pleion, *more*, and καινος,

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* See Princ. of Geol. vol. iii. 1st ed.

cainos, *recent*) a comparative plurality of the same. It may assist the memory of students to remind them, that the *Mi*ocene contain a *mi*nor proportion, and *Pl*iocene a comparative *pl*urality of recent species; and that the greater number of recent species always implies the more modern origin of the strata.

It has sometimes been objected to this nomenclature that certain species of infusoria found in the chalk are still existing, and, on the other hand, the Miocene and Older Pliocene deposits often contain the remains of mammalia, reptiles, and fish, exclusively of extinct species. But the reader must bear in mind that the terms Eocene, Miocene, and Pliocene were originally invented with reference purely to conchological data, and in that sense have always been and are still used by me.

The distribution of the fossil species from which the results before mentioned were obtained in 1830 by M. Deshayes was as follows:—

In the formations of the Pliocene periods, older and newer -	777
In the Miocene - - - - - -	1021
In the Eocene - - - - - -	1238
	3036

Since the year 1830, the number of new living species obtained from different parts of the globe has been exceedingly great, supplying fresh data for comparison, and enabling the paleontologist to correct many erroneous identifications of fossil and recent forms. New species also have been collected in abundance from tertiary formations of every age, while newly discovered groups of strata have filled up gaps in the previously known series. Hence modifications and reforms have been called for in the classification first proposed. The Eocene, Miocene, and Pliocene periods have been made to comprehend certain sets of strata of which the fossils do not always conform strictly in the proportion of recent to extinct species with the definitions first given by me, or which are implied in the etymology of those terms. Of these and other innovations I shall treat more fully in the 14th and 15th chapters.

POST-PLIOCENE FORMATIONS.

I have adopted the term Post-Pliocene for those strata which are sometimes called post-tertiary or modern, and which are characterized by having all the imbedded fossil shells identical with species now living, whereas even the Newer Pliocene, or newest of the tertiary deposits above alluded to, contain always some small proportion of shells of extinct species.

These modern formations, thus defined, comprehend not only those strata which can be shown to have originated since the earth was inhabited by man, but also deposits of far greater extent and thickness, in which no signs of man or his works can be detected. In some of these, of a date long anterior to the times of history and tradition, the bones of extinct quadrupeds have been met with of species which probably never co-existed with the human race, as, for example, the mammoth, mastodon, megatherium, and others, and yet the shells are the same as those now living.

That portion of the post-pliocene group which belongs to the human epoch, and which is sometimes called *Recent*, forms a very unimportant feature in the geological structure of the earth's crust. I have shown, however, in "The Principles," where the recent changes of the earth illustrative of geology are described at length, that the deposits accumulated at the bottom of lakes and seas within the last 4000 or 5000 years can neither be insignificant in volume or extent. They lie hidden, for the most part, from our sight; but we have opportunities of examining them at certain points where newly-gained land in the deltas of rivers has been cut through during floods, or where coral reefs are growing rapidly, or where the bed of a sea or lake has been heaved up by subterranean movements and laid dry. Their age may be recognized either by our finding in them the bones of man in a fossil state, that is to say, imbedded in them by natural causes, or by their containing articles fabricated by the hands of man.

Thus at Puzzuoli, near Naples, marine strata are seen containing fragments of sculpture, pottery, and the remains of buildings, together with innumerable shells retaining in part their colour, and of the same species as those now inhabiting the Bay of Baiæ. The uppermost of these beds is about 20 feet above the level of the sea. Their emergence can be proved to have taken place since the beginning of the sixteenth century.* Now here, as in almost every instance where any alterations of level have been going on in historical periods, it is found that rocks containing shells, all, or nearly all, of which still inhabit the neighbouring sea, may be traced for some distance into the interior, and often to a considerable elevation above the level of the sea. Thus, in the country round Naples, the post-pliocene strata, consisting of clay and horizontal beds of volcanic tuff, rise at certain points to the height of 1500 feet. Although the marine shells are exclusively of living species, they are not accompanied like those on the coast at Puzzuoli by any traces of man or his works. Had any such been discovered, it would have afforded to the antiquary and geologist matter of great surprise, since it would have shown that man was an inhabitant of that part of the globe, while the materials composing the present hills and plains of Campania were still in the progress of deposition at the bottom of the sea; whereas we know that for nearly 3000 years, or from the times of the earliest Greek colonists, no material revolution in the physical geography of that part of Italy has occurred.

In Ischia, a small island near Naples, composed in like manner of marine and volcanic formations, Dr. Philippi collected in the stratified tuff and clay ninety-two species of shells of existing species. In the centre of Ischia, the lofty hill called Epomeo, or San Nicola, is composed of greenish indurated tuff, of a prodigious thickness, inter-

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* See Principles, Index, "Serapis."

stratified in some parts with marl, and here and there with great beds of solid lava. Visconti ascertained by trigonometrical measurement that this mountain was 2605 feet above the level of the sea. Not far from its summit, at the height of about 2000 feet, as also near Moropano, a village only 100 feet lower, on the southern declivity of the mountain, I collected, in 1828, many shells of species now inhabiting the neighbouring gulf. It is clear, therefore, that the great mass of Epomeo was not only raised to its present height, but was also *formed* beneath the waters, within the post-pliocene period.

It is a fact, however, of no small interest, that the fossil shells from these modern tuffs of the volcanic region surrounding the Bay of Baiæ, although none of them extinct, indicate a slight want of correspondence between the ancient fauna and that now inhabiting the Mediterranean. Philippi informs us that when he and M. Scacchi had collected ninety-nine species of them, he found that only one, *Pecten medius*, now living in the Red Sea, was absent from the Mediterranean. Notwithstanding this, he adds, "the condition of the sea when the tufaceous beds were deposited must have been considerably different from its present state; for *Tellina striata* was then common, and is now rare; *Lucina spinosa* was both more abundant and grew to a larger size: *Lucina fragilis*, now rare, and hardly measuring 6 lines, then attained the enormous dimensions of 14 lines, and was extremely abundant; and *Ostrea lamellosa*, Broc., no longer met with near Naples, existed at that time, and attained a size so large that one lower valve has been known to measure 5 inches 9 lines in length, 4 inches in breadth, 1½ inch in thickness, and weighed 26½ ounces."*

There are other parts of Europe where no volcanic action manifests itself at the surface, as at Naples, whether by the eruption of lava or by earthquakes, and yet where the land and bed of the adjoining sea are undergoing upheaval. The motion is so gradual as to be insensible to the inhabitants, being only ascertainable by careful scientific measurements compared after long intervals. Such an upward movement has been proved to be in progress in Norway and Sweden throughout an area about 1000 miles N. and S., and for an unknown distance E. and W., the amount of elevation always increasing as we proceed towards the North Cape, where it may equal 5 feet in a century. If we could assume that there had been an average rise of 2½ feet in each hundred years for the last fifty centuries, this would give an elevation of 125 feet in that period. In other words, it would follow that the shores, and a considerable area of the former bed of the Baltic and North Sea, had been uplifted vertically to that amount, and converted into land in the course of the last 5000 years. Accordingly, we find near Stockholm, in Sweden, horizontal beds of sand, loam, and marl containing the same peculiar assemblage of testacea which now live in the brackish waters of the Baltic. Mingled with these, at different depths, have been detected various works of

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* Geol. Quart. Journ. vol. ii. Memoirs, p. 15.

art implying a rude state of civilization, and some vessels built before the introduction of iron, the whole marine formation having been upraised, so that the upper beds are now 60 feet higher than the surface of the Baltic. In the neighbourhood of these recent strata, both to the north-west and south of Stockholm, other deposits similar in mineral composition occur, which ascend to greater heights, in which precisely the same assemblage of fossil shells is met with, but without any intermixture of human bones or fabricated articles.

On the opposite or western coast of Sweden, at Uddevalla, post-pliocene strata, containing recent shells, not of that brackish water character peculiar to the Baltic, but such as now live in the northern ocean, ascend to the height of 200 feet; and beds of clay and sand of the same age attain elevations of 300 and even 700 feet in Norway, where they have been usually described as "raised beaches." They are, however, thick deposits of submarine origin, spreading far and wide, and filling valleys in the granite and gneiss, just as the tertiary formations, in different parts of Europe, cover or fill depressions in the older rocks.

It is worthy of remark, that, although the fossil fauna characterizing these upraised sands and clays consists exclusively of existing northern species of testacea, yet, according to Lovén (an able living naturalist of Norway), the species do not constitute such an assemblage as now inhabits corresponding latitudes in the German Ocean. On the contrary, they decidedly represent a more arctic fauna.* In order to find the same species flourishing in equal abundance, or in many cases to find them at all, we must go northwards to higher latitudes than Uddevalla in Sweden, or even nearer the pole than Central Norway.

Judging by the uniformity of climate now prevailing from century to century, and the insensible rate of variation in the organic world in our own times, we may presume that an extremely lengthened period was required even for so slight a modification of the molluscous fauna, as that of which the evidence is here brought to light. On the other hand, we have every reason for inferring on independent grounds (namely, the rate of upheaval of land in modern times) that the antiquity of the deposits in question must be very great. For if we assume, as before suggested, that the mean rate of continuous vertical elevation has amounted to 2½ feet in a century (and this is probably a high average), it would require 27,500 years for the sea-coast to attain the height of 700 feet, without making allowance for any pauses such as are now experienced in a large part of Norway, or for any oscillations of level.

In England, buried ships have been found in the ancient and now deserted channels of the Rother in Sussex, of the Mersey in Kent, and the Thames near London. Canoes and stone hatchets have been dug up, in almost all parts of the kingdom, from peat and shell-marl; but there is no evidence, as in Sweden, Italy, and many other parts

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* Quart. Geol. Journ. 4 Mems. p. 48.

of the world, of the bed of the sea, and the adjoining coast, having been uplifted bodily to considerable heights within the human period. Recent strata have been traced along the coasts of Peru and Chili, inclosing shells in abundance, all agreeing specifically with those now swarming in the Pacific. In one bed of this kind, in the island of San Lorenzo, near Lima, Mr. Darwin found, at the altitude of 85 feet above the sea, pieces of cotton-thread, plaited rush, and the head of a stalk of Indian corn, the whole of which had evidently been imbedded with the shells. At the same height on the neighbouring mainland, he found other signs corroborating the opinion that the ancient bed of the sea had there also been uplifted 85 feet since the region was first peopled by the Peruvian race.* But similar shelly masses are also met with at much higher elevations, at innumerable points between the Chilian and Peruvian Andes and the sea-coast, in which no human remains were ever, or in all probability ever will be, discovered.

In the West Indies, also, in the island of Guadaloupe, a solid limestone occurs at the level of the sea-beach, enveloping human skeletons. The stone is extremely hard, and chiefly composed of comminuted shell and coral, with here and there some entire corals and shells, of species now living in the adjacent ocean. With them are included arrow-heads, fragments of pottery, and other articles of human workmanship. A limestone with similar contents has been formed, and is still forming, in St. Domingo. But there are also more ancient rocks in the West Indian Archipelago, as in Cuba, near the Havanna, and in other islands, in which are shells identical with those now living in corresponding latitudes; some well-preserved, others in a state of casts, all referable to the post-pliocene period.

I have already described in the seventh chapter, p. 84., what would be the effect of oscillations and changes of level in any region drained by a great river and its tributaries, supposing the area to be first depressed several hundred feet, and then re-elevated. I believe that such changes in the relative level of land and sea have actually occurred in the post-pliocene era in the hydrographical basin of the Mississippi and in that of the Rhine. The accumulation of fluviatile matter in a delta during a slow subsidence may raise the newly gained land superficially at the same rate at which its foundations sink, so that these may go down hundreds or thousands of feet perpendicularly, and yet the sea bordering the delta may always be excluded, the whole deposit continuing to be terrestrial or freshwater in character. This appears to have happened in the deltas both of the Po and Ganges, for recent artesian borings, penetrating to the depth of 400 feet, have there shown that fluviatile strata, with shells of recent species, together with ancient surfaces of land supporting turf and forests, are depressed hundreds of feet below the sea level.† Should these countries be once more slowly upraised, the rivers would

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* Journal, p. 451.

† See Principles, 8th ed. pp. 260—268., 9th ed. 257—280.

carve out valleys through the horizontal and unconsolidated strata as they rose, sweeping away the greater portion of them, and leaving mere fragments in the shape of terraces skirting newly-formed alluvial plains, as monuments of the former levels at which the rivers ran. Of this nature are "the bluffs," or river cliffs, now bounding the valley of the Mississippi throughout a large portion of its "course." The upper portions of these bluffs which at Natches and elsewhere often rise to the height of 200 feet above the alluvial plain, consist of loam containing land and freshwater shells of the genera *Helix*, *Pupa*, *Succinea*, and *Lymnea*, of the same species as those now inhabiting the neighbouring forests and swamps. In the same loam also are found the bones of the Mastodon, Elephant, Megalonyx, and other extinct quadrupeds.*

I have endeavoured to show that the deposits forming the delta and alluvial plain of the Mississippi consist of sedimentary matter, extending over an area of 30,000 square miles, and known in some parts to be several hundred feet deep. Although we cannot estimate correctly how many years it may have required for the river to bring down from the upper country so large a quantity of earthy matter—the data for such a computation being as yet incomplete—we may still approximate to a minimum of the time which such an operation must have taken, by ascertaining experimentally the annual discharge of water by the Mississippi, and the mean annual amount of solid matter contained in its waters. The lowest estimate of the time required would lead us to assign a high antiquity, amounting to many tens of thousands of years to the existing delta, the origin of which is nevertheless an event of yesterday when contrasted with the terraces, formed of the loam above mentioned. The materials of the bluffs were produced during the first part of a great oscillation of level which depressed to a depth of 200 feet a larger area than the modern delta and plain of the Mississippi, and then restored the whole region to its former position.†

Loess of the Valley of the Rhine.—A similar succession of geographical changes, attended by the production of a fluviatile formation, singularly resembling that which bounds the great plain of the Mississippi, seems to have occurred in the hydrographical basin of the Rhine, since the time when that basin had already acquired its present outline of hill and valley. I allude to the deposit provincially termed *loess* in part of Germany, or *lehm* in Alsace, filled with land and freshwater shells of existing species. It is a finely comminuted sand or pulverulent loam of a yellowish grey colour, consisting chiefly of argillaceous matter combined with a sixth part of carbonate of lime, and a sixth of quartzose and micaceous sand. It often contains calcareous sandy concretions or nodules, rarely exceeding the size of a man's head. Its entire thickness amounts, in some places, to between 200 and 300 feet; yet there are often no signs of stratification in the

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* See Principles of Geol. 9th ed., and Lyell's Second Visit to the United States, vol. ii. p. 257.

† Lyell's Second Visit to the United States, vol. ii. chap. xxxiv.

mass, except here and there at the bottom, where there is occasionally a slight intermixture of drifted materials derived from subjacent rocks. Unsolidified as it is, and of so perishable a nature, that every streamlet flowing over it cuts out for itself a deep gully, it usually terminates in a vertical cliff, from the surface of which land-shells are seen here and there to project in relief. In all these features it presents a precise counterpart to the loess of the Mississippi. It is so homogeneous as generally to exhibit no signs of stratification, owing, probably, to its materials having been derived from a common source, and having been accumulated by a uniform action. Yet it displays in some few places decided marks of successive deposition, where coarser and finer materials alternate, especially near the bottom. Calcareous concretions, also enclosing land-shells, are sometimes arranged in horizontal layers. It is a remarkable deposit, from its position, wide extent, and thickness, its homogeneous mineral composition, and freshwater origin. Its distribution clearly shows that after the great valley of the Rhine, from Schaffhausen to Bonn, had acquired its present form, having its bottom strewed over with coarse gravel, a period arrived when it became filled up from side to side with fine mud, probably deposited during river inundations; and it is also clear that similar mud and silt were thrown down contemporaneously in the valleys of the principal tributaries of the Rhine.

Thus, for example, it may be traced far into Würtemberg, up the valley of the Neckar, and from Frankfort, up the valley of the Main, to above Dettelbach. I have also seen it spreading over the country of Mayence, Eppelsheim, and Worms, on the left bank of the Rhine, and on the opposite side on the table-land above the Bergstrasse, between Wiesloch and Bruchsal, where it attains a thickness of 200 feet. Near Strasburg, large masses of it appear at the foot of the Vosges on the left bank, and at the base of the mountains of the Black Forest on the right bank. The Kaiserstuhl, a volcanic mountain which stands in the middle of the plain of the Rhine near Freiburg, has been covered almost everywhere with this loam, as have the extinct volcanos between Coblentz and Bonn. Near Andernach, in the Kirchweg, the loess containing the usual shells alternates with volcanic matter; and over the whole are strewed layers of pumice, lapilli, and volcanic sand, from 10 to 15 feet thick, very much resembling the ejections under which Pompeii lies buried. There is no passage at this upper junction from the loess into the pumiceous superstratum; and this last follows the slope of the hill, just as it would have done had it fallen in showers from the air on a declivity partly formed of loess.

But, in general, the loess overlies all the volcanic products, even those between Neuwied and Bonn, which have the most modern aspect; and it has filled up in part the crater of the Roderberg, an extinct volcano near Bonn. In 1833 a well was sunk at the bottom of this crater, through 70 feet of loess, in part of which were the usual calcareous concretions.

The interstratification above alluded to of loess with layers of pumice and volcanic ashes, has led to the opinion that both during and since its deposition some of the last volcanic eruptions of the Lower Eifel have taken place. Should such a conclusion be adopted, we should be called upon to assign a very modern date to these eruptions. This curious point, therefore, deserves to be reconsidered; since it may possibly have happened that the waters of the Rhine, swollen by the melting of snow and ice, and flowing at a great height through a valley choked up with loess, may have swept away the loose superficial scoriæ and pumice of the Eifel volcanos, and spread them out occasionally over the yellow loam. Sometimes, also, the melting of snow on the slope of small volcanic cones may have given rise to local floods capable of sweeping down light pumice into the adjacent low grounds.

The first idea which has occurred to most geologists, after examining the loess between Mayence and Basle, is to imagine that a great lake once extended throughout the valley of the Rhine between those two places. Such a lake may have sent off large branches up the course of the Main, Neckar, and other tributary valleys, in all of which large patches of loess are now seen. The barrier of the lake might be placed somewhere in the narrow and picturesque gorge of the Rhine between Bingen and Bonn. But this theory fails altogether to explain the phenomena; when we discover that that gorge itself has once been filled with loess, which must have been tranquilly deposited in it, as also in the lateral valley of the Lahn, communicating with the gorge. The loess has also overspread the high adjoining platform near the village of Plaidt above Andernach. Nay, on proceeding farther down to the north, we discover that the hills which skirt the great valley between Bonn and Cologne have loess on their flanks, which also covers here and there the gravel of the plain as far as Cologne, and the nearest rising grounds.

Besides these objections to the lake theory, the loess is met with near Basle, capping hills more than 1200 feet above the sea; so that a barrier of land capable of separating the supposed lake from the ocean would require to be, at least, as high as the mountains called the Siebengebirge, near Bonn, the loftiest summit of which, the Oehlberg, is 1209 feet above the Rhine and 1369 feet above the sea. It would be necessary, moreover, to place this lofty barrier somewhere below Cologne, or precisely where the level of the land is now lowest.

Instead, therefore, of supposing one continuous lake of sufficient extent and depth to allow of the simultaneous accumulation of the loess, at various heights, throughout the whole area where it now occurs, I formerly suggested that, subsequently to the period when the countries now drained by the Rhine and its tributaries had nearly acquired their actual form and geographical features, they were again depressed gradually by a movement like that now in progress on the west coast of Greenland.* In proportion as the whole

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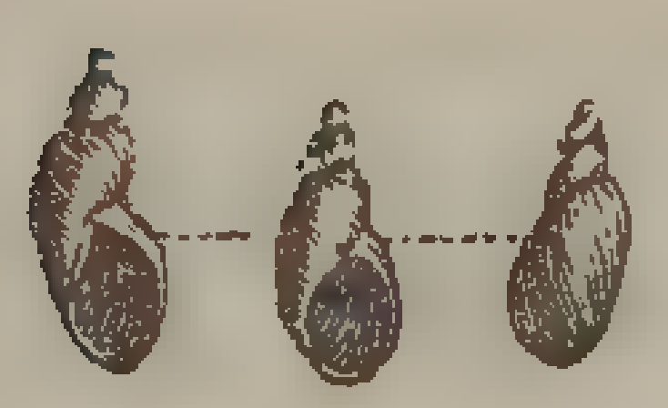
* Princ. of Geol. 3d edition, 1834, vol. iii. p. 414.

district was lowered, the general fall of the waters between the Alps and the ocean was lessened; and both the main and lateral valleys, becoming more subject to river inundations, were partially filled up with fluviatile silt, containing land and freshwater shells. When a thickness of many hundred feet of loess had been thrown down slowly by this operation, the whole region was once more upheaved gradually. During this upward movement most of the fine loam would be carried off by the denuding power of rains and rivers; and thus the original valleys might have been re-excavated, and the country almost restored to its pristine state, with the exception of some masses and patches of loess such as still remain, and which, by their frequency and remarkable homogeneousness of composition and fossils, attest the ancient continuity and common origin of the whole. By imagining these oscillations of level, we dispense with the necessity of erecting and afterwards removing a mountain barrier sufficiently high to exclude the ocean from the valley of the Rhine during the period of the accumulation of the loess.

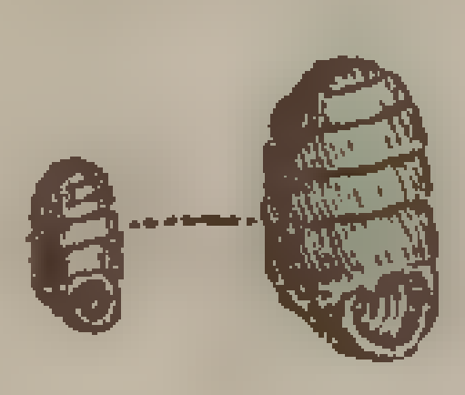
The proportion of land-shells of the genera *Helix*, *Pupa*, and *Bulimus* is very large in the loess; but in many places aquatic species of the genera *Lymnea*, *Paludina*, and *Planorbis* are also found. These may have been carried away during floods from shallow pools and marshes bordering the river; and the great extent of marshy ground caused by the wide overflowings of rivers above supposed would favour the multiplication of amphibious mollusks, such as the *Succinea* (fig. 106.), which is almost everywhere characteristic of this formation, and is sometimes accompanied, as near Bonn, by another species, *S. amphibia* (fig. 34. p. 29.). Among other abundant fossils are *Helex plebeium* and *Pupa muscorum*. (See Figures.)

Fig. 106.



Succinea elongata.

Fig. 107.



Pupa muscorum.

Fig. 108.

Helix plebeium.

Both the terrestrial and aquatic shells preserved in the loess are of most fragile and delicate structure, and yet they are almost invariably perfect and uninjured. They must have been broken to pieces had they been swept along by a violent inundation. Even the colour of some of the land-shells, as that of *Helix nemoralis*, is occasionally preserved.

Bones of vertebrated animals are rare in the loess, but those of the mammoth, horse, and some other quadrupeds have been met with. At the village of Binningen, and the hills called Bruder Holz, near Basle, I found the vertebræ of fish, together with the usual shells. These vertebræ, according to M. Agassiz, belong decidedly to the Shark family, perhaps to the genus *Lamna*. In explanation of their occurrence among land and freshwater shells, it may be stated that certain fish of this family ascend the Senegal, Amazon, and other great rivers, to the distance of several hundred miles from the ocean.*

At Cannstadt, near Stuttgardt, in a valley also belonging to the hydrographical basin of the Rhine, I have seen the loess pass downwards into beds of calcareous tuff and travertin. Several valleys in northern Germany, as that of the Ilm at Weimar, and that of the Tonna, north of Gotha, exhibit similar masses of modern limestone filled with recent shells of the genera *Planorbis*, *Lymnea*, *Paludina*, &c., from 50 to 80 feet thick, with a bed of loess much resembling that of the Rhine, occasionally incumbent on them. In these modern limestones used for building, the bones of *Elephas primigenius*, *Rhinoceros tichorhinus*, *Ursus spelæus*, *Hyæna spelæa*, with the horse, ox, deer, and other quadrupeds, occur; and in 1850 Mr. H. Credner and I obtained in a quarry at Tonna, at the depth of 15 feet, inclosed in the calcareous rock and surrounded with dicotyledonous leaves and petrified leaves, four eggs of a snake of the size of the largest European Coluber, which, with three others, were lying in a series, or string.

They are, I believe, the first reptilian remains which have been met with in strata of this age.

The agreement of the shells in these cases with recent European species enables us to refer to a very modern period the filling up and re-excavation of the valleys; an operation which doubtless consumed a long period of time, since which the mammiferous fauna has undergone a considerable change.

CHAPTER XI.

NEWER PLIOCENE PERIOD.—BOULDER FORMATION.

Drift of Scandinavia, northern Germany, and Russia—Its northern origin—Not all of the same age—Fundamental rocks polished, grooved, and scratched—Action of glaciers and icebergs—Fossil shells of glacial period—Drift of eastern Norfolk—Associated freshwater deposit—Bent and folded strata lying on undisturbed beds—Shells on Moel Tryfane—Ancient glaciers of North Wales—Irish drift.

AMONG the different kinds of alluvium described in the seventh chapter, mention was made of the boulder formation in the north of Europe, the peculiar characters of which may now be considered, as it belongs in part to the post-pliocene, and partly to the newer pliocene, period. I shall first allude briefly to that portion of it which extends from Finland and the Scandinavian mountains to the north of Russia, and the low countries bordering the Baltic, and which has been traced southwards as far as the eastern coast of England. This formation

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* Proceedings Geol. Soc. No. 43. p. 222.

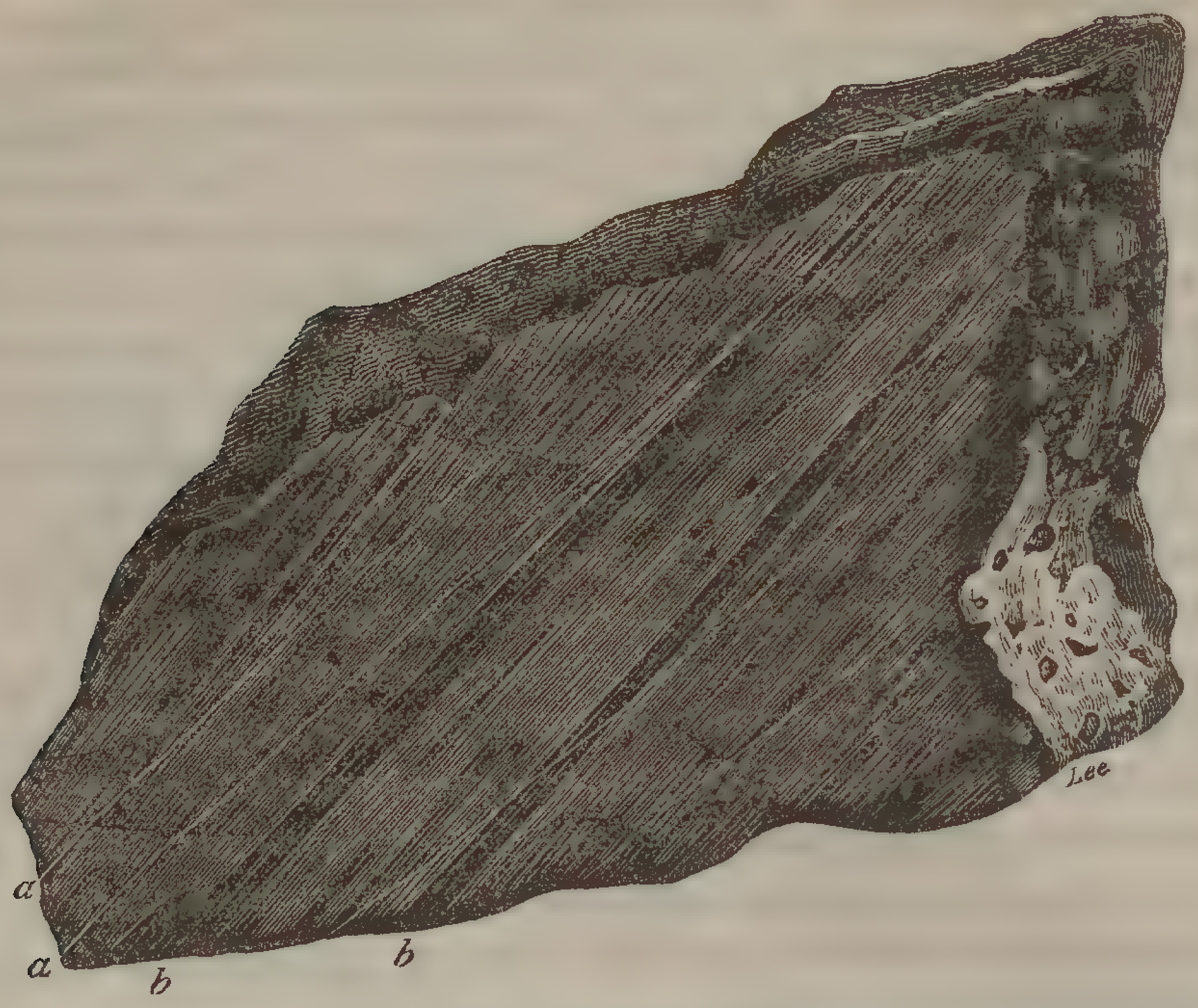
consists of mud, sand, and clay, sometimes stratified, but often wholly devoid of stratification, for a depth of more than a hundred feet. To this unstratified form of the deposit, the name of *till* has been applied in Scotland. It generally contains numerous fragments of rocks, some angular and others rounded, which have been derived from formations of all ages, both fossiliferous, volcanic, and hypogene, and which have often been brought from great distances. Some of the travelled blocks are of enormous size, several feet or yards in diameter; their average dimensions increasing as we advance northwards. The till is almost everywhere devoid of organic remains, unless where these have been washed into it from older formations; so that it is chiefly from relative position that we must hope to derive a knowledge of its age.

Although a large proportion of the boulder deposit, or "northern drift," as it has sometimes been called, is made up of fragments brought from a distance, and which have sometimes travelled many hundred miles, the bulk of the mass in each locality consists of the ruins of subjacent or neighbouring rocks; so that it is red in a region of red sandstone, white in a chalk country, and grey or black in a district of coal and coal-shale.

The fundamental rock on which the boulder formation reposes, if it consists of granite, gneiss, marble, or other hard stone capable of permanently retaining any superficial markings which may have been imprinted upon it, is usually smoothed or polished, and exhibits parallel striæ and furrows having a determinate direction. This direction, both in Europe and North America, is evidently connected with the course taken by the erratic blocks in the same district, being from north to south, or if it be 20 or 30 degrees to the east or west of north, always corresponding to the direction in which the large angular and rounded stones have travelled. These stones themselves also are often furrowed and scratched on more than one side.

In explanation of such phenomena I may refer the student to what was said of the action of glaciers and icebergs in the Principles of Geology. (ch. xv.) It is ascertained that hard stones, frozen into a moving mass of ice, and pushed along under the pressure of that mass, scoop out long rectilinear furrows or grooves parallel to each other on the subjacent solid rock. (See fig. 109.) Smaller scratches and striæ are made on the polished surface by crystals or projecting edges of the hardest minerals, just as a diamond cuts glass. The recent polishing and striation of limestone by coast-ice carrying boulders even as far south as the coast of Denmark, has been observed by Dr. Forchhammer, and helps us to conceive how large icebergs, running aground on the bed of the sea, may produce similar furrows on a grander scale. An account was given so long ago as the year 1822, by Scoresby, of icebergs seen by him drifting along in latitudes 69° and 70° N., which rose above the surface from 100 to 200 feet, and measured from a few yards to a mile in circumference. Many of them were loaded with beds of earth and rock, of such thickness that the weight was conjectured to be from 50,000 to 100,000

Fig. 109.



Limestone polished, furrowed, and scratched by the glacier of Rosenlaui, in Switzerland. (Agassiz.)
a a. White streaks or scratches, caused by small grains of flint frozen into the ice.
b b. Furrows.

tons. A similar transportation of rocks is known to be in progress in the southern hemisphere, where boulders included in ice are far more frequent than in the north. One of these icebergs was encountered in 1839, in mid-ocean, in the antarctic regions, many hundred miles from any known land, sailing northwards, with a large erratic block firmly frozen into it. In order to understand in what manner long and straight grooves may be cut by such agency, we must remember that these floating islands of ice have a singular steadiness of motion, in consequence of the larger portion of their bulk being sunk deep under water, so that they are not perceptibly moved by the winds and waves even in the strongest gales. Many had supposed that the magnitude commonly attributed to icebergs by unscientific navigators was exaggerated, but now it appears that the popular estimate of their dimensions has rather fallen within than beyond the truth. Many of them, carefully measured by the officers of the French exploring expedition of the Astrolabe, were between 100 and 225 feet high above water, and from 2 to 5 miles in length. Captain d'Urville ascertained one of them which he saw floating in the Southern Ocean to be 13 miles long and 100 feet high, with walls perfectly vertical. The submerged portions of such islands must, according to the weight of ice relatively to sea-water, be from six to eight times more considerable than the part which is visible, so that the mechanical power they might exert when fairly set in motion must be prodigious.* A large proportion of these floating masses of ice are supposed not to be derived from terrestrial glaciers

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* T. L. Hayes, Boston Journ. Nat. Hist. 1844.

(Principles, ch. xv.), but to be formed at the foot of cliffs by the drifting of snow from the land over the frozen surface of the sea.

We know that in Switzerland, when glaciers laden with mud and stones melt away at their lower extremity before reaching the sea, they leave wherever they terminate a confused heap of unstratified rubbish, called "a moraine," composed of mud, sand, and pieces of all the rocks with which they were loaded. We may expect, therefore, to find a formation of the same kind, resulting from the liquefaction of icebergs, in tranquil water. But, should the action of a current intervene at certain points or at certain seasons, then the materials will be sorted as they fall, and arranged in layers according to their relative weight and size. Hence there will be passages from *till*, as it is called in Scotland, to stratified clay, gravel, and sand, and intercalations of one in the other.

I have yet to mention another appearance connected with the boulder formation, which has justly attracted much attention in Norway and other parts of Europe. Abrupt pinnacles and outstanding ridges of rock are often observed to be polished and furrowed on the north side, or on the side facing the region from which the erratics have come; while on the other, which is usually steeper and often perpendicular, called the "lee-side," such superficial markings are wanting. There is usually a collection on this lee-side of boulders and gravel, or of large angular fragments. In explanation we may suppose that the north side was exposed, when still submerged, to the action of icebergs, and afterwards, when the land was upheaved, of coast ice, which ran aground upon shoals, or was *packed* on the beach; so that there would be great wear and tear on the seaward slope, while, on the other, gravel and boulders might be heaped up in a sheltered position.

Northern origin of erratics.—That the erratics of northern Europe have been carried southward cannot be doubted; those of granite, for example, scattered over large districts of Russia and Poland, agree precisely in character with rocks of the mountains of Lapland and Finland; while the masses of gneiss, syenite, porphyry, and trap, strewed over the low sandy countries of Pomerania, Holstein, and Denmark, are identical in mineral characters with the mountains of Norway and Sweden.

It is found to be a general rule in Russia, that the smaller blocks are carried to greater distances from their point of departure than the larger; the distance being sometimes 800 and even 1000 miles from the nearest rocks from which they were broken off; the direction having been from N.W. to S.E., or from the Scandinavian mountains over the seas and low lands to the south-east. That its accumulation throughout this area took place in part during the post-pliocene period is proved by its superposition at several points to strata containing recent shells. Thus, for example, in European Russia, MM. Murchison and De Verneuil found in 1840, that the flat country between St. Petersburg and Archangel, for a distance of 600 miles, consisted of horizontal strata, full of shells similar to those now inhabiting the arctic sea, on which rested the boulder formation, containing large erratics.

In Sweden, in the immediate neighbourhood of Upsala, I had observed, in 1834, a ridge of stratified sand and gravel, in the midst of which occurs a layer of marl, evidently formed originally at the bottom of the Baltic, by the slow growth of the mussel, cockle, and other marine shells of living species intermixed with some proper to fresh water. The marine shells are all of dwarfish size, like those now inhabiting the brackish waters of the Baltic; and the marl, in which myriads of them are imbedded, is now raised more than 100 feet above the level of the Gulf of Bothnia. Upon the top of this ridge repose several huge erratics, consisting of gneiss for the most part unrounded, from 9 to 16 feet in diameter, and which must have been brought into their present position since the time when the neighbouring gulf was already characterized by its peculiar fauna.* Here, therefore, we have proof that the transport of erratics continued to take place, not merely when the sea was inhabited by the existing testacea, but when the north of Europe had already assumed that remarkable feature of its physical geography, which separates the Baltic from the North Sea, and causes the Gulf of Bothnia to have only one fourth of the saltness belonging to the ocean. In Denmark, also, recent shells have been found in stratified beds, closely associated with the boulder clay.

It was stated that in Russia the erratics diminished generally in size in proportion as they are traced farther from their source. The same observation holds true in regard to the average bulk of the Scandinavian boulders, when we pursue them southwards, from the south of Norway and Sweden through Denmark and Westphalia. This phenomenon is in perfect harmony with the theory of ice-islands floating in a sea of variable depth; for the heavier erratics require icebergs of a larger size to buoy them up; and, even when there are no stones frozen in, more than seven eighths, and often nine tenths, of a mass of drift ice is under water. The greater, therefore, the volume of the iceberg, the sooner would it impinge on some shallower part of the sea; while the smaller and lighter floes, laden with finer mud and gravel, may pass freely over the same banks, and be carried to much greater distances. In those places, also, where in the course of centuries blocks have been carried southwards by coast-ice, having been often stranded and again set afloat in the direction of a prevailing current, the blocks will diminish in size the farther they travel from their point of departure for two reasons: first, because they will be repeatedly exposed to wear and tear by the action of the waves; secondly, because the largest blocks are seldom without divisional planes or "joints," which cause them to split when weathered. Hence, as often as they start on a fresh voyage, becoming buoyant by coast-ice which has frozen on to them, one portion of the mass is detached from the rest. A recent examination (in 1852)

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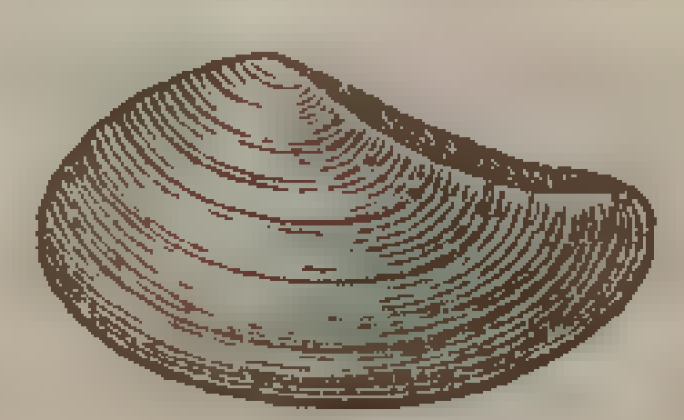
* See paper by the author, Phil. Trans. 1835, p. 15.

of several trains of huge erratics in lat. 42° 50′ N. in the United States, in Berkshire, on the western confines of Massachusetts, has convinced me that this cause has been very influential both in reducing the size of erratics, and in restoring angularity to blocks which would otherwise be rounded in proportion to their distance from their original starting point.

The "northern drift" of the most southern latitudes is usually of the highest antiquity. In Scotland it rests immediately on the older rocks, and is covered by stratified sand and clay, usually devoid of fossils, but in which, at certain points near the east and west coast, as, for example, in the estuaries of the Tay and Clyde, marine shells have been discovered. The same shells have also been met with in the north, at Wick in Caithness, and on the shores of the Moray Frith. The principal deposit on the Clyde occurs at the height of about 70 feet, but a few shells have been traced in it as high as 554 feet above the sea. Although a proportion of between 85 or 90 in 100 of the imbedded shells are of recent species, the remainder are unknown; and even many which are recent now inhabit more northern seas, where we may, perhaps, hereafter find living representatives of some of the unknown fossils. The distance to which erratic blocks have been carried southwards in Scotland, and the course they have taken, which is often wholly independent of the present position of hill and valley, favours the idea that ice-rafts rather than glaciers were in general the transporting agents. The Grampians in Forfarshire and in Perthshire are from 3000 to 4000 feet high. To the southward lies the broad and deep valley of Strathmore, and to the south of this again rise the Sidlaw Hills * to the height of 1500 feet and upwards. On the highest summits of this chain, formed of sandstone and shale, and at various elevations, are found huge angular fragments of mica-schist, some 3 and others 15 feet in diameter, which have been conveyed for a distance of at least 15 miles from the nearest Grampian rocks from which they could have been detached. Others have been left strewed over the bottom of the large intervening vale of Strathmore.

Fig. 110.
Astarte borealis.

Fig. 111.
Leda oblonga.



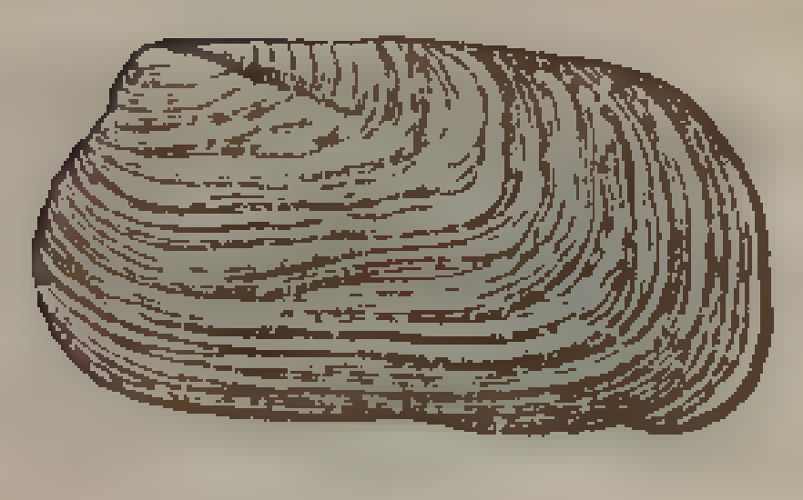


Fig. 112.
Saxicava rugosa.

Fig. 113.
Pecten islandicus.

Fig. 114.
Natica clausa.

Fig. 115.
Trophon clathratum.

Northern shells common in the drift of the Clyde, in Scotland.

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* See above, section, p. 48.

Still farther south on the Pentland Hills, at the height of 1100 feet above the sea, Mr. Maclaren has observed a fragment of mica-schist weighing from 8 to 10 tons, the nearest mountain composed of this formation being 50 miles distant.*

The testaceous fauna of the boulder period, in Scotland, England, and Ireland, has been shown by Prof. E. Forbes to contain a much smaller number of species than that now belonging to the British seas, and to have been also much less rich in species than the Older Pliocene fauna of the crag which preceded it. Yet the species are nearly all of them now living either in the British or more northern seas, the shells of more arctic latitudes being the most abundant and the most wide spread throughout the entire area of the drift from north to south.

This extensive range of the fossils can by no means be explained by imagining the mollusca of the drift to have been inhabitants of a deep sea, where a more uniform temperature prevailed. On the contrary, many species were littoral, and others belonged to a shallow sea, not above 100 feet deep, and very few of them lived, according to Prof. E. Forbes, at greater depths than 300 feet.

From what was before stated it will appear that the boulder formation displays almost everywhere, in its mineral ingredients, a strange heterogeneous mixture of the ruins of adjacent lands, with stones both angular and rounded, which have come from points often very remote. Thus we find it in our eastern counties, as in Norfolk, Suffolk, Cambridge, Huntingdon, Bedford, Hertford, Essex, and Middlesex, containing stones from the Silurian and Carboniferous strata, and from the lias, oolite, and chalk, all with their peculiar fossils, together with trap, syenite, mica-schist, granite, and other crystalline rocks. A fine example of this singular mixture extends to the very suburbs of London, being seen on the summit of Muswell Hill, Highgate. But south of London the northern drift is wanting, as, for example, in the Wealds of Surrey, Kent, and Sussex.

Norfolk drift.—The drift can nowhere be studied more advantageously in England than in the cliffs of the Norfolk coast between Happisburgh and Cromer. Vertical sections, having an ordinary height of from 50 to 70 feet, are there exposed to view for a distance of about 20 miles. The name of diluvium was formerly given to it by those who supposed it to have been produced by the violent action of a sudden and transient deluge, but the term drift has been substituted by those who reject this hypothesis. Here, as elsewhere, it consists for the most part of clay, loam, and sand, in part stratified, in part devoid of stratification. Pebbles, together with some large boulders of granite, porphyry, greenstone, lias, chalk, and other transported rocks, are interspersed, especially through the till. That some of the granitic and other fragments came from Scandinavia I have no doubt, after having myself traced the course of the continuous stream of blocks from Norway and Sweden to Denmark, and

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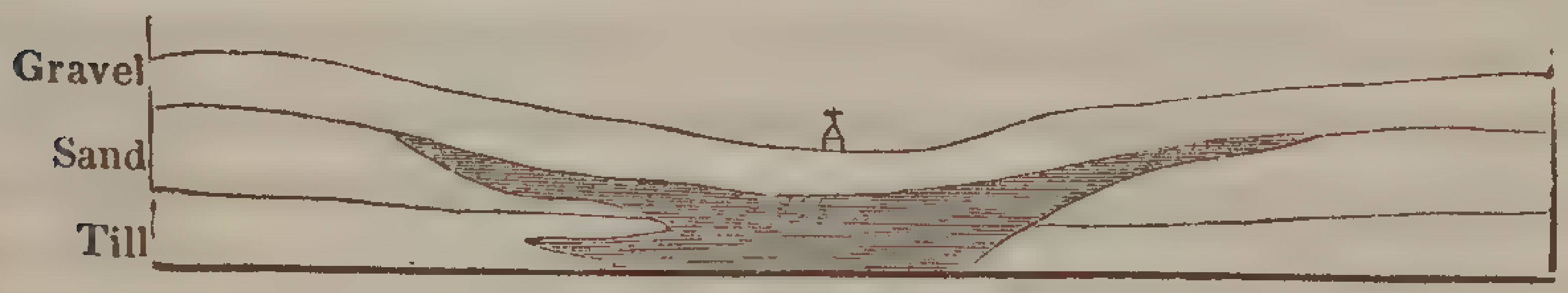
* Geol. of Fife, &c., p. 220.

across the Elbe, through Westphalia, to the borders of Holland. We need not be surprised to find them reappear on our eastern coast between the Tweed and the Thames, regions not half so remote from parts of Norway as are many Russian erratics from the sources whence they came.

White chalk rubble, unmixed with foreign matter, and even huge fragments of solid chalk, also occur in many localities in these Norfolk cliffs. No fossils have been detected in this drift which can positively be referred to the era of its accumulation; but at some points it overlies a freshwater formation containing recent shells, and at others it is blended with the same in such a manner as to force us to conclude that both were contemporaneously deposited.

Fig. 116.



The shaded portion consists of Freshwater beds.
Intercalation of freshwater beds and of boulder clay and sand at Mundesley.

This interstratification is expressed in the annexed figure, the dark mass indicating the position of the freshwater beds, which contain much vegetable matter, and are divided into thin layers. The imbedded shells belong to the genera *Planorbis*, *Lymnea*, *Paludina*, *Unio*, *Cyclas*, and others, all of British species, except a minute *Paludina* now inhabiting France. (See fig. 117.)

Fig. 117.

Paludina marginata, Michaud. (*P. minuta*, Strickland.)
The middle figure is of the natural size.

The *Cyclas* (fig. 118.) is merely a remarkable variety of the common English species. The scales and teeth of fish of the genera Pike, Perch, Roach, and others, accompany these shells; but the

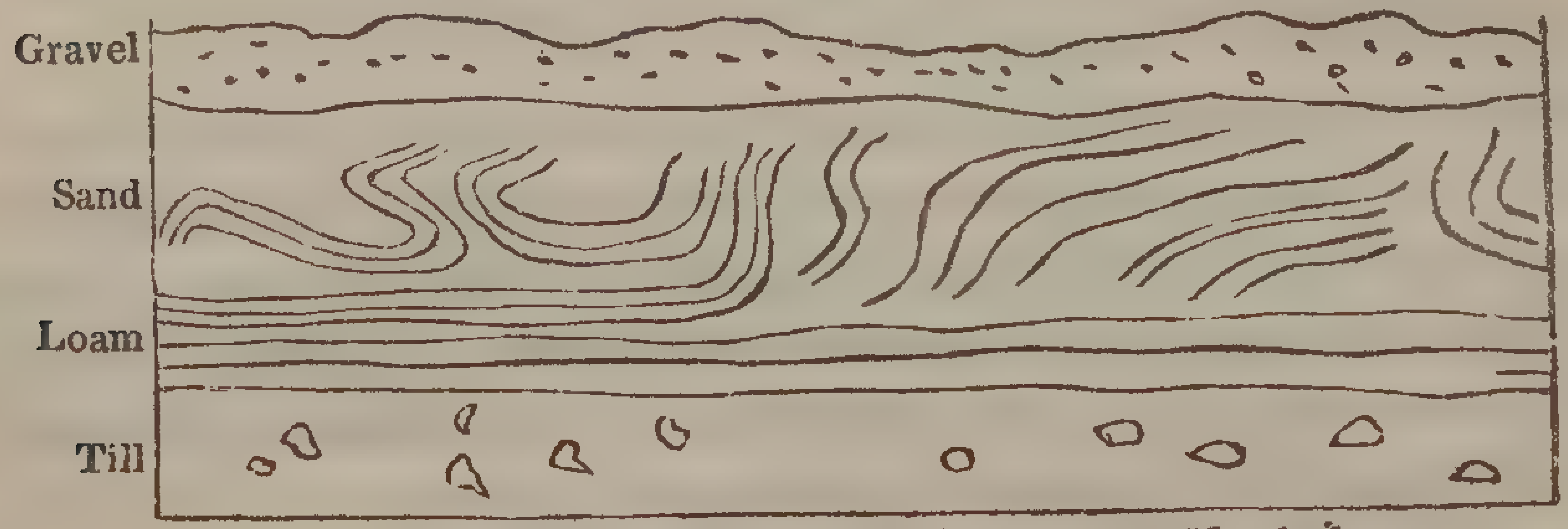
Fig. 118.

Cyclas (*Pisidium*) *amnica*, var.?
The two middle figures are of the natural size.

species are not considered by M. Agassiz to be identical with known British or European kinds.

The series of formations in the cliffs of eastern Norfolk, now under consideration, beginning with the lowest, is as follows: — First, chalk; secondly, patches of a marine tertiary formation, called the Norwich Crag, hereafter to be described; thirdly, the freshwater beds already mentioned; and lastly, the drift. Immediately above the chalk, or crag, when that is present, is found here and there a buried forest, or a stratum in which the stools and roots of trees stand in their natural position, the trunks having been broken short off and imbedded with their branches and leaves. It is very remarkable that the strata of the overlying boulder formation have often undergone great derangement at points where the subjacent forest bed and chalk remain undisturbed. There are also cases where the upper portion of the boulder deposit has been greatly deranged, while the lower beds of the same have continued horizontal. Thus the annexed section (fig. 119.) represents a cliff about 50 feet high, at the bottom of which is *till*, or unstratified clay, containing boulders, having an even horizontal surface, on which repose conformably beds of laminated clay and sand about 5 feet thick, which, in their turn, are succeeded by vertical, bent, and contorted layers of sand and loam 20 feet thick, the whole being covered by flint gravel. Now the curves of the variously coloured beds of loose sand, loam, and pebbles are so complicated that not only may we sometimes find portions of

Fig. 119.



Cliff 50 feet high between Bacton Gap and Mundesley.

Fig. 120.

Folding of the strata between East and West Runton.

Fig. 121.

Section of concentric beds west of Cromer.

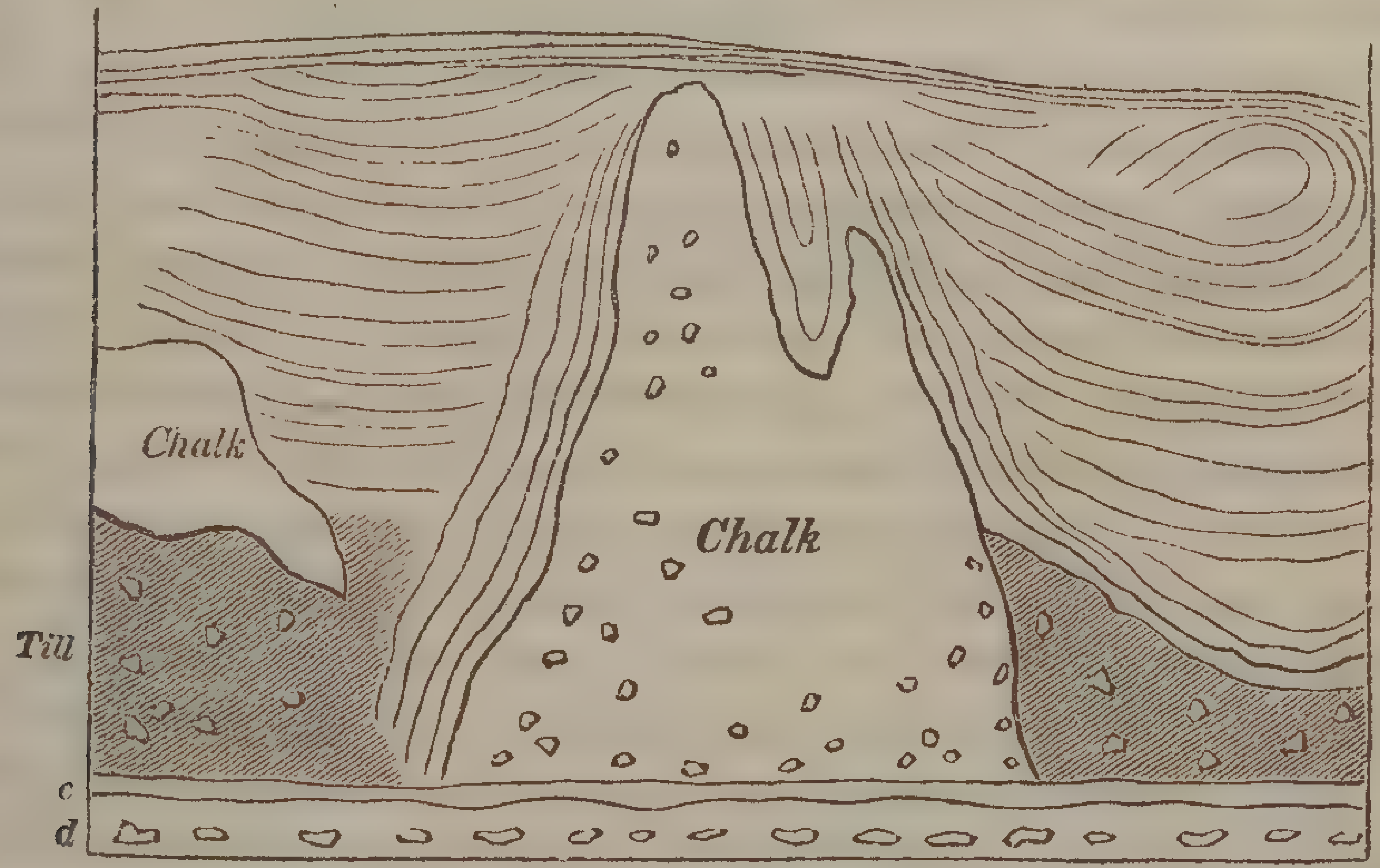
1. Blue clay. 3. Yellow sand.
2. White sand. 4. Striped loam and clay.
5. Laminated blue clay.

them which maintain their verticality to a height of 10 or 15 feet, but they have also been folded upon themselves in such a manner that continuous layers might be thrice pierced in one perpendicular boring.

At some points there is an apparent folding of the beds round a central nucleus, as at *a*, fig. 120., where the strata seem bent round a small mass of chalk; or, as in fig. 121., where the blue clay, No. 1., is in the centre; and where the other strata, 2, 3, 4, 5, are coiled round it; the entire mass being 20 feet in perpendicular height. This appearance of concentric arrangement around a nucleus is, nevertheless, delusive, being produced by the intersection of beds bent into a convex shape; and that which seems the nucleus being, in fact, the innermost bed of the series, which has become partially visible by the removal of the protuberant portions of the outer layers.

To the north of Cromer are other fine illustrations of contorted drift reposing on a floor of chalk horizontally stratified and having a level surface. These phenomena, in themselves sufficiently difficult of explanation, are rendered still more anomalous by the occasional inclosure in the drift of huge fragments of chalk many yards in diameter. One striking instance occurs west of Sherringham, where an enormous pinnacle of chalk, between 70 and 80 feet in height, is flanked on both sides by vertical layers of loam, clay, and gravel. (Fig. 122.)

Fig. 122.



Included pinnacle of chalk at Old Hythe point, west of Sherringham.
d. Chalk with regular layers of chalk flints.
c. Layer called "the pan," of loose chalk, flints, and marine shells of recent species, cemented by oxide of iron.

This chalky fragment is only one of many detached masses which have been included in the drift, and forced along with it into their present position. The level surface of the chalk *in situ* (*d*) may be traced for miles along the coast, where it has escaped the violent movements to which the incumbent drift has been exposed.*

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* For a full account of the drift of East Norfolk, see a paper by the author, Phil. Mag. No. 104. May, 1840.

We are called upon, then, to explain how any force can have been exerted against the upper masses, so as to produce movements in which the subjacent strata have not participated. It may be answered that, if we conceive the *till* and its boulders to have been drifted to their present place by ice, the lateral pressure may have been supplied by the stranding of ice-islands. We learn, from the observations of Messrs. Dease and Simpson in the polar regions, that such islands, when they run aground, push before them large mounds ot shingle and sand. It is therefore probable that they often cause great alterations in the arrangement of pliant and incoherent strata forming the upper part of shoals or submerged banks, the inferior portions of the same remaining unmoved. Or many of the complicated curvatures of these layers of loose sand and gravel may have been due to another cause, the melting on the spot of icebergs and coast ice in which successive deposits of pebbles, sand, ice, snow, and mud, together with huge masses of rock fallen from cliffs, may have become interstratified. Ice-islands so constituted often capsize when afloat, and gravel once horizontal may have assumed, before the associated ice was melted, an inclined or vertical position. The packing of ice forced up on a coast may lead to similar derangement in a frozen conglomerate of sand or shingle, and, as Mr. Trimmer has suggested*, alternate layers of earthy matter may have sunk down slowly during the liquefaction of the intercalated ice, so as to assume the most fantastic and anomalous positions, while the strata below, and those afterwards thrown down above, may be perfectly horizontal.

There is, however, still another mode in which some of these bendings may have been produced. When a railway embankment is thrown across a marsh or across the bed of a drained lake, we frequently find that the foundation, consisting of peat and shell-marl, or of quicksand and mud, gives way, and sinks as fast as the embankment is raised at the top. At the same time, there is often seen at the distance of many yards, in some neighbouring part of the morass, a squeezing up of pliant strata, the amount of upheaval depending on the volume and weight of materials heaped upon the embankment. In 1852 I saw a remarkable instance of such a downward and lateral pressure, in the suburbs of Boston (U. S.), near the South Cove. With a view of converting part of an estuary overflowed at high tide into dry land, they had thrown into it a vast load of stones and sand, upwards of 900,000 cubic yards in volume. Under this weight the mud had sunk down many yards vertically. Meanwhile the adjoining bottom of the estuary, supporting a dense growth of salt-water plants, only visible at low tide, had been pushed gradually upward, in the course of many months, so as to project five or six feet above high water mark. The upraised mass was bent into five or six anticlinal folds, and below the upper layer of turf, consisting of salt-marsh plants, mud was seen above the level of high tide, full of sea shells, such as *Mya arenaria*, *Modiola plicatula*, *Sanguinolaria*

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* Quart. Journ. Geol. Soc. vol. vii. p. 22.

fusca, *Nassa obsoleta*, *Natica triseriata*, and others. In some of these curved beds the layers of shells were quite vertical. The upraised area was 75 feet wide, and several hundred yards long. Were an equal load, melted out of icebergs or coast-ice, thrown down on the floor of a sea, consisting of soft mud and sand, similar disturbances and contortions might result in some adjacent pliant strata, yet the underlying more solid rocks might remain undisturbed, and newer formations, perfectly horizontal, might be afterwards superimposed.

A buried forest has been adverted to as underlying the drift on the coast of Norfolk. At the time when the trees grew, there must have been dry land over a large area, which was afterwards submerged, so as to allow a mass of stratified and unstratified drift, 200 feet and more in thickness, to be superimposed. The undermining of the cliffs by the sea in modern times has enabled us to demonstrate, beyond all doubt, the fact of this superposition, and that the forest was not formed along the present coast-line. Its situation implies a subsidence of several hundred feet since the commencement of the drift period, after which there must have been an upheaval of the same ground; for the forest bed of Norfolk is now again so high as to be exposed to view at many points at low water; and this same upward movement may explain why the *till*, which is conceived to have been of submarine origin, is now met with far inland, and on the summit of hills.

The boulder formation of the west of England, observed in Lancashire, Cheshire, Shropshire, Staffordshire, and Worcestershire, contains in some places marine shells of recent species, rising to various heights, from 100 to 350 feet above the sea. The erratics have come partly from the mountains of Cumberland, and partly from those of Scotland.

But it is on the mountains of North Wales that the "Northern drift," with its characteristic marine fossils, reaches its greatest altitude. On Moel Tryfane, near the Menai Straits, Mr. Trimmer met with shells of the species commonly found in the drift at the height of 1392 feet above the level of the sea.

It is remarkable that in the same neighbourhood where there is evidence of so great a submergence of the land during part of the glacial period, we have also the most decisive proofs yet discovered in the British Isles of sub-aerial glaciers. Dr. Buckland published in 1842 his reasons for believing that the Snowdonian mountains in Caernarvonshire were formerly covered with glaciers, which radiated from the central heights through the seven principal valleys of that chain, where striæ and flutings are seen on the polished rocks directed towards as many different points of the compass. He also described the "moraines" of the ancient glaciers, and the rounded "bosses" or small flattened domes of polished rock, such as the action of moving glaciers is known to produce in Switzerland, when gravel, sand, and boulders, underlying the ice, are forced along over a foundation of hard stone. Mr. Darwin, and subsequently Prof.

Ramsay, have confirmed Dr. Buckland's views in regard to these Welsh glaciers. Nor indeed was it to be expected that geologists should discover proofs of icebergs having abounded in the area now occupied by the British Isles in the Pleistocene period without sometimes meeting with the signs of contemporaneous glaciers which covered hills even of moderate elevation between the 50th and 60th degrees of latitude.

In Ireland the "drift" exhibits the same general characters and fossil remains as in Scotland and England; but in the southern part of that island, Prof. E. Forbes and Capt. James found in it some shells which show that the glacial sea communicated with one inhabited by a more southern fauna. Among other species in the south, they mention at Wexford and elsewhere the occurrence of *Nucula Cobboldiæ* (see fig. 125. p. 156.) and *Turritella incrassata* (a crag fossil); also a southern form of *Fusus*, and a *Mitra* allied to a Spanish species.*

CHAPTER XII.

Difficulty of interpreting the phenomena of drift before the glacial hypothesis was adopted — Effects of intense cold in augmenting the quantity of alluvium — Analogy of erratics and scored rocks in North America and Europe — Bayfield on shells in drift of Canada — Great subsidence and re-elevation of land from the sea, required to account for glacial appearances — Why organic remains so rare in northern drift — Mastodon giganteus in United States — Many shells and some quadrupeds survived the glacial cold — Alps an independent centre of dispersion of erratics — Alpine blocks on the Jura — Whether transported by glaciers or floating ice — Recent transportation of erratics from the Andes to Chiloe — Meteorite in Asiatic drift.

It will appear from what was said in the last chapter of the marine shells characterizing the boulder formation, that nine-tenths or more of them belong to species still living. The superficial position of "the drift" is in perfect accordance with its imbedded organic remains, leading us to refer its origin to a modern period. If, then, we encounter so much difficulty in the interpretation of monuments relating to times so near our own — if in spite of their recent date they are involved in so much obscurity — the student may ask, not without reasonable alarm, how we can hope to decipher the records of remoter ages.

To remove from the mind as far as possible this natural feeling of discouragement, I shall endeavour in this chapter to prove that what seems most strikingly anomalous, in the "erratic formation," as some call it, is really the result of that glacial action which has already been

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* Forbes, Memoirs of Geol. Survey of Great Britain, vol. i. p. 377.

alluded to. If so, it was to be expected that so long as the true origin of so singular a deposit remained undiscovered, erroneous theories and terms would be invented in the effort to solve the problem. These inventions would inevitably retard the reception of more correct views which a wider field of observation might afterwards suggest.

The term "diluvium" was for a time the popular name of the boulder formation, because it was referred by some to the deluge, while others retained the name as expressive of their opinion that a series of diluvial waves raised by hurricanes and storms, or by earthquakes, or by the sudden upheaval of land from the bed of the sea, had swept over the continents, carrying with them vast masses of mud and heavy stones, and forcing these stones over rocky surfaces so as to polish and imprint upon them long furrows and striæ.

But no explanation was offered why such agency should have been developed more energetically in modern times than at former periods of the earth's history, or why it should be displayed in its fullest intensity in northern latitudes; for it is important to insist on the fact, that the boulder formation is a *northern* phenomenon. Even the southern extension of the drift, or the large erratics found in the Alps and the surrounding lands, especially their occurrence round the highest parts of the chain, offers such an exception to the general rule as confirms the glacial hypothesis; for it shows that the transportation of stony fragments to great distances, and the striation, polishing, and grooving of solid floors of rock, are here again intimately connected with accumulations of perennial snow and ice.

That there is some intimate connection between a cold or northern climate and the various geological appearances now commonly called glacial, cannot be doubted by any one who has compared the countries bordering the Baltic with those surrounding the Mediterranean. The smoothing and striation of rocks and erratics, are traced from the sea-shore to the height of 3000 feet above the level of the Baltic, whereas such phenomena are wholly wanting in countries bordering the Mediterranean; and their absence is still more marked in the equatorial parts of Asia, Africa, and America; but when we cross the southern tropic, and reach Chili and Patagonia, we again encounter the boulder formation, between the latitude 41° S. and Cape Horn, with precisely the same characters which it assumes in Europe. The evidence as to climate derived from the organic remains of the drift is, as we have seen, in perfect harmony with the conclusions above alluded to, the former habits of the species of mollusca being accurately ascertainable, inasmuch as they belong to species still living, and known to have at present a wide range in northern seas.

But if we are correct in assuming that the northern hemisphere was considerably colder than now during the period under consideration, owing probably to the greater area and height of arctic lands, and to the quantity of icebergs which such a geographical state of things would generate, it may be well to reflect before we proceed farther on the entire modification which extreme cold would produce in the operation of those causes spoken of in the sixth chapter as most active in the formation of alluvium. A large part of the materials derived from the detritus of rocks, which in warm climates would go to form deltas, or would be regularly stratified by marine currents, would, under arctic influences, assume a superficial and alluvial character. Instead of mud being carried farther from a coast than sand, and sand farther out than pebbles,—instead of dense stratified masses being heaped up in limited areas, along the borders of continents,—nearly the whole materials, whether coarse or fine, would be conveyed by ice to equal distances, and huge fragments, which water alone could never move, would be borne for hundreds of miles without having their edges worn or fractured: and the earthy and stony masses, when melted out of the frozen rafts, would be scattered at random over the submarine bottom, whether on mountain tops or in low plains, with scarcely any relation to the inequalities of the ground, settling on the crests or ridges of hills in tranquil water as readily as in valleys and ravines. Occasionally, in those deep and uninhabited parts of the ocean, never reached by any but the finest sediment in a normal state of things, the bottom would become densely overspread by gravel, mud, and boulders.

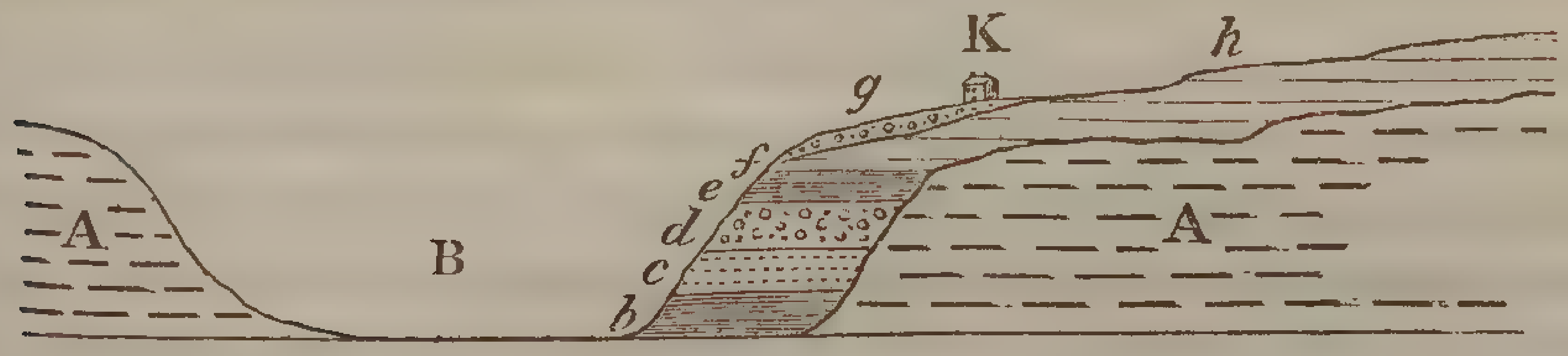
In the Western Hemisphere, both in Canada and as far south as the 40th and even 38th parallel of latitude in the United States, we meet with a repetition of all the peculiarities which distinguish the European boulder formation. Fragments of rock have travelled for great distances from north to south: the surface of the subjacent rock is smoothed, striated, and fluted; unstratified mud or *till* containing boulders is associated with strata of loam, sand, and clay, usually devoid of fossils. Where shells are present, they are of species still living in northern seas, and half of them identical with those already enumerated as belonging to European drift 10 degrees of latitude farther north. The fauna also of the glacial epoch in North America is less rich in species than that now inhabiting the adjacent sea, whether in the Gulf of St. Lawrence, or off the shores of Maine, or in the Bay of Massachusetts. At the southern extremity of its course, moreover, it presents an analogy with the drift of the south of Ireland, by blending with a more southern fauna, as for example at Brooklyn near New York, in lat. 41° N., where, according to MM. Redfield and Desor, *Venus mercenaria* and other southern species of shells begin to occur as fossils in the drift.

The extension on the American continent of the range of erratics during the Pleistocene period to lower latitudes than they reached in Europe, agrees well with the present southward deflection of the isothermal lines, or rather the lines of equal winter temperature. It seems that formerly, as now, a more extreme climate and a more abundant supply of floating ice prevailed on the western side of the Atlantic.

Another resemblance between the distribution of the drift fossils in Europe and North America has yet to be pointed out. In Norway, Sweden, and Scotland, as in Canada and the United States, the marine shells are confined to very moderate elevations above the sea (between 100 and 700 feet), while the erratic blocks and the grooved and polished surfaces of rock extend to elevations of several thousand feet.

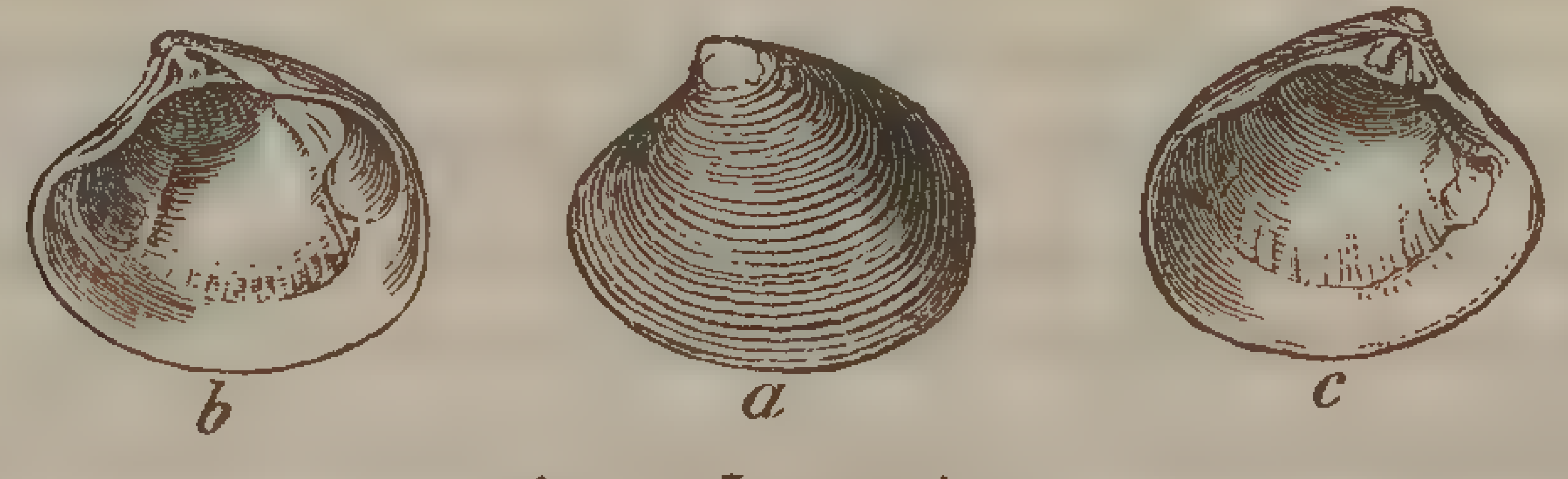
I described in 1839 the fossil shells collected by Captain Bayfield from strata of drift at Beauport near Quebec, in lat. 47°, and drew from them the inference that they indicated a more northern climate, the shells agreeing in great part with those of Uddevalla in Sweden.* The shelly beds attain at Beauport and the neighbourhood a height of 200, 300, and sometimes 400 feet above the sea, and dispersed through some of them are large boulders of granite, which could not have been propelled by a violent current, because the accompanying fragile shells are almost all entire. They seem, therefore, said Captain Bayfield, writing in 1838, to have been dropped down from melting ice, like similar stones which are now annually deposited in the St. Lawrence.† I visited this locality in 1842, and made the annexed section, fig. 123., which will give an idea of the general position of the drift in Canada and the United States. I imagine that the whole of the valley B was once filled up with the beds *b*, *c*, *d*, *e*, *f*, which were deposited during a period of subsidence, and that subsequently the higher country (*h*) was submerged and overspread with drift. The partial re-excavation of B took place when this region was again uplifted above the sea to its present height. Among the twenty-three species of fossil shells collected by me from these beds at Beauport, all were of recent northern species, except one, which is unknown as living, and may be extinct (see fig. 124.). I also examined the same formation farther up the valley of the St. Lawrence, in the suburbs

Fig. 123.



K. Mr. Ryland's house.
h. Clay and sand of higher grounds, with *Saxicava*, &c.
g. Gravel with boulders.
f. Mass of *Saxicava rugosa*, 12 feet thick.
e. Sand and loam with *Mya truncata*, *Scalaria Grœnlandica*, &c.
d. Drift, with boulders of syenite, &c.
c. Yellow sand.
b. Laminated clay, 25 feet thick.
A. Horizontal lower Silurian strata.
B. Valley re-excavated.

Fig. 124.



Astarte Laurentiana.

a. Outside. *b*. Inside of right valve. *c*. Left valve.

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* Geol. Trans. 2d series, vol. vi. p. 135. Mr. Smith of Jordanhill had arrived at similar conclusions as to climate from the shells of the Scotch Pleistocene deposits.

† Proceedings of Geol Soc. No. 63. p. 119.

of Montreal, where some of the beds of loam are filled with great numbers of the *Mytilus edulis*, or our common European mussel, retaining both its valves and purple colour. This shelly deposit, containing *Saxicava rugosa* and other characteristic marine shells, also occurs at an elevated point on the mountain of Montreal, 450 feet above the level of the sea.*

In my account of Canada and the United States, published in 1845, I announced the conclusion to which I had then arrived, that to explain the position of the erratics and the polished surfaces of rocks, and their striæ and flutings, we must assume first a gradual submergence of the land in North America, after it had acquired its present outline of hill and valley, cliff and ravine, and then its re-emergence from the ocean. When the land was slowly sinking, the sea which bordered it was covered with islands of floating ice coming from the north, which, as they grounded on the coast and on shoals, pushed along such loose materials of sand and pebbles as lay strewed over the bottom. By this force all angular and projecting points were broken off, and fragments of hard stone, frozen into the lower surface of the ice, had power to scoop out grooves in the subjacent solid rock. The sloping beach, as well as the floor of the ocean, might be polished and scored by this machinery; but no flood of water, however violent, or however great the quantity of detritus or size of the rocky fragments swept along by it, could produce such long, perfectly straight and parallel furrows, as are everywhere visible in the Niagara district, and generally in the region north of the 40th parallel of latitude.†

By the hypothesis of such a slow and gradual subsidence of the land we may account for the fact that almost everywhere in N. America and Northern Europe the boulder formation rests on a polished and furrowed surface of rock,—a fact by no means obliging us to imagine, as some think, that the polishing and grooving action was, as a whole, anterior in date to the transportation of the erratics. During the successive depression of high land, varying originally in height from 1000 to 3000 feet above the sea level, every portion of the surface would be brought down by turns to the level of the ocean, so as to be converted first into a coast-line, and then into a shoal; and at length, after being well scored by the stranding upon it year after year of large masses of coast-ice and occasional icebergs, might be sunk to a depth of several hundred fathoms. By the constant depression of land, the coast would recede farther and farther from the successively formed zones of polished and striated rock, each outer zone becoming in its turn so deep under water as to be no longer grated upon by the heaviest icebergs. Such sunken areas would then simply serve as receptacles of mud, sand, and boulders dropped from melting ice, perhaps to a depth scarcely, if at all, inhabited by testacea and zoophytes. Meanwhile, during the formation of the unstratified and unfossiliferous mass in deeper water, the smoothing

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* Travels in N. America, vol. ii. p. 141.

† Ibid. p. 99. chap. xix.

and furrowing of shoals and beaches would still go on elsewhere upon and near the coast in full activity. If at length the subsidence should cease, and the direction of the movement of the earth's crust be reversed, the sunken area covered with drift would be slowly reconverted into land. The boulder deposit, before emerging, would then for a time be brought within the action of the waves, tides, and currents, so that its upper portion, being partially disturbed, would have its materials rearranged and stratified. Streams also flowing from the land would in some places throw down layers of sediment upon the *till*. In that case, the order of superposition will be, first and uppermost, sand, loam, and gravel occasionally fossiliferous; secondly, an unstratified and unfossiliferous mass called *till*, for the most part of much older date than the preceding, with angular erratics, or with boulders interspersed; and, thirdly, beneath the whole, a surface of polished and furrowed rock. Such a succession of events seems to have prevailed very widely on both sides of the Atlantic, the travelled blocks having been carried in general from the North Pole southwards, but mountain chains having in some cases served as independent centres of dispersion, of which the Alps present the most conspicuous example.

It is by no means rare to meet with boulders imbedded in drift which are worn flat on one or more of their sides, the surface being at the same time polished, furrowed, and striated. They may have been so shaped in a glacier before they reached the sea, or when they were fixed in the bottom of an iceberg as it ran aground. We learn from Mr. Charles Martins that the glaciers of Spitzbergen project from the coast into a sea between 100 and 400 feet deep; and that numbers of striated pebbles or blocks are there seen to disengage themselves from the overhanging masses of ice as they melt, so as to fall at once into deep water.*

That they should retain such markings when again upraised above the sea ought not to surprise us, when we remember that rippled sands, and the cracks in clay dried between high and low water, and the foot-tracks of animals and rain-drops impressed on mud, and other superficial markings, are all found fossil in rocks of various ages.

On the other hand, it is not difficult to account for the absence in many districts of striated and scored pebbles and boulders in glacial deposits, for they may have been exposed to the action of the waves on a coast while it was sinking beneath or rising above the sea. No shingle on an ordinary sea-beach exhibits such striæ, and at a very short distance from the termination of a glacier every stone in the bed of the torrent which gushes out from the melting ice is found to have lost its glacial markings by being rolled for a distance even of a few hundred yards.

The usual dearth of fossil shells in glacial clays well fitted to preserve organic remains may, perhaps, be owing, as already hinted, to the absence of testacea in the deep sea, where the undisturbed accu-

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* Bulletin Soc. Géol. de France, tom. iv. 2de sér. p. 1121.

mulation of boulders melted out of coast-ice and icebergs may take place. In the Ægean and other parts of the Mediterranean, the zero of animal life, according to Prof. E. Forbes, is approached at a depth of about 300 fathoms. In tropical seas it would descend farther down, just as vegetation ascends higher on the mountains of hot countries. Near the pole, on the other hand, the same zero would be reached much sooner both on the hills and in the sea. If the ocean was filled with floating bergs, and a low temperature prevailed in the northern hemisphere during the glacial period, even the shallow part of the sea might have been uninhabitable, or very thinly peopled with living beings. It may also be remarked that the melting of ice in some fiords in Norway freshens the water so as to destroy marine life, and famines have been caused in Iceland by the stranding of icebergs drifted from the Greenland coast, which have required several years to melt, and have not only injured the hay harvest by cooling the atmosphere, but have driven away the fish from the shore by chilling and freshening the sea.

If the cold of the glacial epoch came on slowly, if it was long before it reached its greatest intensity, and again if it abated gradually, we may expect to find the earliest and latest formed drift less barren of organic remains than that deposited during the coldest period. We may also expect that along the southern limits of the drift during the whole glacial epoch, there would be an intimate association of transported matter of northern origin with fossil-bearing sediment, whether marine or freshwater, belonging to more southern seas, rivers, and continents.

That in the United States, the *Mastodon giganteus* was very abundant after the drift period is evident from the fact that entire skeletons of this animal are met with in bogs and lacustrine deposits occupying hollows in the drift. They sometimes occur in the bottom even of small ponds recently drained by the agriculturist for the sake of the shell marl. I examined one of these spots at Geneseo in the state of New York, from which the bones, skull, and tusk of a Mastodon had been procured in the marl below a layer of black peaty earth, and ascertained that all the associated freshwater and land shells were of a species now common in the same district. They consisted of several species of *Lymnea*, of *Planorbis bicarinatus*, *Physa heterostropha*, &c.

In 1845 no less than six skeletons of the same species of Mastodon were found in Warren County, New Jersey, 6 feet below the surface, by a farmer who was digging out the rich mud from a small pond which he had drained. Five of these skeletons were lying together, and a large part of the bones crumbled to pieces as soon as they were exposed to the air. But nearly the whole of the other skeleton, which lay about 10 feet apart from the rest, was preserved entire, and proved the correctness of Cuvier's conjecture respecting this extinct animal, namely, that it had twenty ribs like the living elephant. From the clay in the interior within the ribs, just where the contents of the stomach might naturally have been looked for, seven bushels of vegetable matter were extracted. I submitted some of this matter to Mr. A. Henfrey of London for microscopic examination, and he informs me that it consists of pieces of small twigs of a coniferous tree of the Cypress family, probably the young shoots of the white cedar, *Thuja occidentalis,* still a native of North America, on which therefore we may conclude that this extinct Mastodon once fed.

Another specimen of the same quadruped, the most complete and probably the largest ever found, was exhumed in 1845 in the town of Newburg, New York, the length of the skeleton being 25 feet, and its height 12 feet. The anchylosing of the last two ribs on the right side afforded Dr. John C. Warren a true gauge for the space occupied by the intervertebrate substance, so as to enable him to form a correct estimate of the entire length. The tusks when discovered were 10 feet long, but a part only could be preserved. The large proportion of animal matter in the tusk, teeth, and bones of some of these fossil mammalia is truly astonishing. It amounts in some cases, as Dr. C. T. Jackson has ascertained by analysis, to 27 per cent.; so that when all the earthy ingredients are removed by acids, the form of the bone remains as perfect, and the mass of animal matter is almost as firm, as in a recent bone subjected to similar treatment.

It would be rash, however, to infer from such data that these quadrupeds were mired in *modern* times, unless we use that term strictly in a geological sense. I have shown that there is a fluviatile deposit in the valley of the Niagara, containing shells of the genera *Melania, Lymnea, Planorbis, Valvata, Cyclas, Unio, Helix,* &c., all of recent species, from which the bones of the great Mastodon have been taken in a very perfect state. Yet the whole excavation of the ravine, for many miles below the Falls, has been slowly effected since that fluviatile deposit was thrown down.

Whether or not, in assigning a period of more than 30,000 years for the recession of the Falls from Queenstown to their present site, I have over or under estimated the time required for that operation, no one can doubt that a vast number of centuries must have elapsed before so great a series of geographical changes were brought about as have occurred since the entombment of this elephantine quadruped. The freshwater gravel which encloses it is decidedly of much more modern origin than the drift or boulder clay of the same region.*

Other extinct animals accompany the *Mastodon giganteus* in the post-glacial deposits of the United States, among which the *Castoroides ohioensis,* Foster and Wyman, a huge rodent allied to the beaver, and *Capybara* may be mentioned. But whether the "loess," and other freshwater and marine strata of the Southern States, in which skeletons of the same Mastodon are mingled with the bones of the Megatherium, Mylodon, and Megalonyx, were contemporaneous with the drift, or were of subsequent date, is a chronological question still open to discussion. It appears clear, however, from what we know of the tertiary fossils of Europe—and I believe the same will hold

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* Travels in N. America, vol. i. chap. ii., and Principles of Geol. chap. xiv.

true in North America—that many species of testacea and some mammalia which existed prior to the glacial epoch, survived that era. As European examples among the warm-blooded quadrupeds, the *Elephas primigenius* and *Rhinoceros tichorhinus* may be mentioned. As to the shells, whether freshwater, terrestrial, or marine, they need not be enumerated here, as allusion will be made to them in the sequel, when the pliocene tertiary fossils of Suffolk are described. The fact is important, as refuting the hypothesis that the cold of the glacial period was so intense and universal as to annihilate all living creatures throughout the globe.

That the cold was greater for a time than it is now in certain parts of Siberia, Europe, and North America, will not be disputed; but, before we can infer the universality of a colder climate, we must ascertain what was the condition of other parts of the northern, and of the whole southern, hemisphere at the time when the Scandinavian, British, and Alpine erratics were transported into their present position. It must not be forgotten that a great deposit of drift and erratic blocks is now in full progress of formation in the southern hemisphere, in a zone corresponding in latitude to the Baltic, and to Northern Italy, Switzerland, France, and England. Should the uneven bed of the southern ocean be hereafter converted by upheaval into land, the hills and valleys will be strewed over with transported fragments, some derived from the antarctic continent, others from islands covered with glaciers, like South Georgia, which must now be centres of the dispersion of drift, although situated in a latitude agreeing with that of the Cumberland mountains in England.

Not only are these operations going on between the 45th and 60th parallels of latitude south of the line, while the corresponding zone of Europe is free from ice; but, what is still more worthy of remark, we find in the southern hemisphere itself, only 900 miles distant from South Georgia, where the perpetual snow reaches to the sea-beach, lands covered with forest, as in Terra del Fuego. There is here no difference of latitude to account for the luxuriance of vegetation in one spot, and the absolute want of it in the other; but among other refrigerating causes in South Georgia may be enumerated the countless icebergs which float from the antarctic zone, and which chill, as they melt, the waters of the ocean, and the surrounding air, which they fill with dense fogs.

I have endeavoured in the "Principles of Geology," chapters 7 and 8., to point out the intimate connexion of climate and the physical geography of the globe, and the dependence of the mean annual temperature, not only on the height of the dry land, but on its distribution in high or low latitudes at particular epochs. If, for example, at certain periods of the past, the antarctic land was less elevated and less extensive than now, while that at the north pole was higher and more continuous, the conditions of the northern and southern hemispheres might have been the reverse of what we now witness in regard to climate, although the mountains of Scandinavia, Scotland, and Switzerland may have been less elevated than at present. But if in both of the polar regions a considerable area of elevated dry land existed, such a concurrence of refrigerating conditions in both hemispheres might have created for a time an intensity of cold never experienced since; and such probably was the state of things during that period of submergence to which I have alluded in this chapter.

Alpine erratics.— Although the arctic regions constitute the great centre from which erratics have travelled southwards in all directions in Europe and North America, yet there are some mountains, as I have already stated, like those of North Wales and the Alps, which have served as separate and independent centres for the dispersion of blocks. In illustration of this fact, the Alps deserve particular attention not only from their magnitude, but because they lie beyond the ordinary limits of the "northern drift" of Europe, being situated between the 44th and 47th degrees of north latitude. On the flanks of these mountains, and on the Subalpine ranges of hills or plains adjoining them, those appearances which have been so often alluded to, as distinguishing or accompanying the drift, between the 50th and 70th parallels of north latitude, suddenly reappear, to assume in a more southern country their most exaggerated form. Where the Alps are highest, the largest erratic blocks have been sent forth; as, for example, from the regions of Mont Blanc and Monte Rosa, into the adjoining parts of France, Switzerland, Austria, and Italy; while in districts where the great chain sinks in altitude, as in Carinthia, Carniola, and elsewhere, no such rocky fragments, or a few only and of smaller bulk, have been detached and transported to a distance.

In the year 1821, M. Venetz first announced his opinion that the Alpine glaciers must formerly have extended far beyond their present limits, and the proofs appealed to by him in confirmation of this doctrine were afterwards acknowledged by M. Charpentier, who strengthened them by new observations and arguments, and declared, in 1836, his conviction that the glaciers of the Alps must once have reached as far as the Jura, and have carried thither their moraines across the great valley of Switzerland. M. Agassiz, after several excursions in the Alps with M. Charpentier, and after devoting himself some years to the study of glaciers, published, in 1840, an admirable description of them and of the marks which attest the former action of great masses of ice over the entire surface of the Alps and the surrounding country.[*] He pointed out that the surface of every large glacier is strewed over with gravel and stones detached from the surrounding precipices by frost, rain, lightning, or avalanches. And he described more carefully than preceding writers the long lines of these stones, which settle on the sides of the glacier, and are called the lateral moraines; those found at the lower end of the ice being called terminal moraines. Such heaps of earth and boulders every glacier pushes before it when advancing, and leaves behind it when retreating. When the Alpine glacier reaches a lower and warmer

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[*] Agassiz, Etudes sur les Glaciers, and Systême Glacière.

situation, about 3000 or 4000 feet above the sea, it melts so rapidly that, in spite of the downward movement of the mass, it can advance no farther. Its precise limits are variable from year to year, and still more so from century to century; one example being on record of a recession of half a mile in a single year. We also learn from M. Venetz, that whereas, between the eleventh and fifteenth centuries, all the Alpine glaciers were less advanced than now, they began in the seventeenth and eighteenth centuries to push forward, so as to cover roads formerly open, and to overwhelm forests of ancient growth.

These oscillations enable the geologist to note the marks which a glacier leaves behind it as it retrogrades; and among these the most prominent, as before stated, are the terminal moraines, or mounds of unstratified earth and stones, often divided by subsequent floods into hillocks, which cross the valley like ancient earth-works, or embankments made to dam up a river. Some of these transverse barriers were formerly pointed out by Saussure below the glacier of the Rhone, as proving how far it had once transgressed its present boundaries. On these moraines we see many large angular fragments, which, having been carried along on the surface of the ice, have not had their edges worn off by friction; but the greater number of the boulders, even those of large size, have been well rounded, not by the power of water, but by the mechanical force of the ice, which has pushed them against each other, or against the rocks flanking the valley. Others have fallen down the numerous fissures which intersect the glacier, where, being subject to the pressure of the whole mass of ice, they have been forced along, and either well rounded or ground down into sand, or even the finest mud, of which the moraine is largely constituted.

As the terminal moraines are the most prominent of all the monuments left by a receding glacier, so are they the most liable to obliteration; for violent floods or debacles are often occasioned in the Alps by the sudden bursting of what are called glacier-lakes. These temporary sheets of water are caused by the damming up of a river by a glacier which has increased during a succession of cold seasons, and descending from a tributary into the main valley, has crossed it from side to side. On the failure of this icy barrier, the accumulated waters are let loose, which sweep away and level many a transverse mound of gravel and loose boulders below, and spread their materials in confused and irregular beds over the river-plain.

Another mark of the former action of glaciers, in situations where they exist no longer, is the polished, striated, and grooved surfaces of rocks already alluded to. Stones which lie underneath the glacier and are pushed along by it, sometimes adhere to the ice, and as the mass glides slowly along at the rate of a few inches, or at the utmost two or three feet, per day, abrade, groove, and polish the rock, and the larger blocks are reciprocally grooved and polished by the rock on their lower sides. As the forces both of pressure and propulsion are enormous, the sand, acting like emery, polishes the surface; the pebbles, like coarse gravers, scratch and furrow it; and the large stones scoop out grooves in it. Another effect also of this action, not yet adverted to, is called "roches moutonnées." Projecting eminences of rock are smoothed and worn into the shape of flattened domes, where the glaciers have passed over them.

Although the surface of almost every kind of rock, when exposed in the open air, wastes away by decomposition, yet some retain for ages their polished and furrowed exterior; and, if they are well protected by a covering of clay or turf, these marks of abrasion seem capable of enduring for ever. They have been traced in the Alps to great heights above the present glaciers, and to great horizontal distances beyond them.

There are also found, on the sides of the Swiss valleys, round and deep holes with polished sides, such holes as waterfalls make in the solid rock, but in places remote from running waters, and where the form of the surface will not permit us to suppose that any cascade could ever have existed. Similar cavities are common in hard rocks, such as gneiss in Sweden, where they are called *giant caldrons*, and are sometimes 10 feet and more in depth; but in the Alps and Jura they often pass into spoon-shaped excavations and prolonged gutters. We learn from M. Agassiz that hollows of this form are now cut out by streams of water which, after flowing along the surface of a glacier, fall into open fissures in the ice and form a cascade. Here the falling water, causing the gravel and sand at the bottom to rotate, cuts out a round cavity in the rock. But as the glacier moves on, the cascade becomes locomotive, and what would otherwise have been a circular hole is prolonged into a deep groove. The form of the rocky bottom of the valley down which the glacier is moving causes the rents in the ice and these locomotive cascades to be formed again and again, year after year, in exactly the same spots.

Another effect of a glacier is to lodge a ring of stones round the summit of a conical peak which may happen to project through the ice. If the glacier is lowered greatly by melting, these circles of large angular fragments, which are called "perched blocks," are left in a singular situation near the top of a steep hill or pinnacle, the lower parts of which may be destitute of boulders.

Alpine blocks on the Jura.—Now some or all the marks above enumerated,—the moraines, erratics, polished surfaces, domes, striæ, caldrons, and perched rocks, are observed in the Alps at great heights above the present glaciers, and far below their actual extremities; also in the great valley of Switzerland, 50 miles broad; and almost everywhere on the Jura, a chain which lies to the north of this valley. The average height of the Jura is about one-third that of the Alps, and it is now entirely destitute of glaciers; yet it presents almost everywhere similar moraines, and the same polished and grooved surfaces and water-worn cavities. The erratics, moreover, which cover it, present a phenomenon which has astonished and perplexed the geologist for more than half a century. No conclusion can be more incontestable than that these angular blocks of granite, gneiss, and other crystalline formations, came from the Alps, and that they have been brought for a distance of 50 miles and upwards across one of the widest and deepest valleys of the world; so that they are now lodged on the hills and valleys of a chain composed of limestone and other formations, altogether distinct from those of the Alps. Their great size and angularity, after a journey of so many leagues, has justly excited wonder; for hundreds of them are as large as cottages; and one in particular, celebrated under the name of Pierre à Bot, rests on the side of a hill about 900 feet above the lake of Neufchatel, and is no less than 40 feet in diameter.

It will be remarked that these blocks on the Jura offer an exception to the rule before laid down, as applicable in general to erratics, since they have gone from south to north. Some of the largest masses of granite and gneiss have been found to contain 50,000 and 60,000 cubic feet of stone, and one limestone block at Devens, near Bex, which has travelled 30 miles, contains 161,000 cubic feet, its angles being sharp and unworn.*

Von Buch, Escher, and Studer have shown, from an examination of the mineral composition of the boulders, that those on the western Jura, near Neufchatel, have come from the region of Mont Blanc and the Valais; those on the middle parts of the Jura from the Bernese Oberland; and those on the eastern Jura from the Alps of the small cantons, Glaris, Schwytz, Uri, and Zug. The blocks, therefore, of these three great districts have been derived from parts of the Alps nearest to the localities in the Jura where we now find them, as if they had crossed the great valley in a direction at right angles to its length; the most western stream having followed the course of the Rhone; the central, that of the Aar; and the eastern, that of the two great rivers, Reuss and Limmat. The non-intermixture of these groups of travelled fragments, except near their confines, was always regarded as most enigmatical by those who adopted the opinion of Saussure, that they were all whirled along by a rapid current of muddy water rushing from the Alps.

M. Charpentier first suggested, as before mentioned, that the Swiss glaciers once reached continuously to the Jura, and conveyed to them these erratics; but at the same time he conceived that the Alps were formerly higher than now. M. Agassiz, on the other hand, instead of introducing distinct and separate glaciers, suggested that the whole valley of Switzerland might have been filled with ice, and that one great sheet of it extended from the Alps to the Jura, when the two chains were of the same height as now relatively to each other. Such an hypothesis labours under this difficulty, that the difference of altitude, when distributed over a space of 50 miles, gives an inclination of no more than two degrees, or far less than that of any known glaciers. It has, however, since received the able support of Professor James Forbes, in his excellent work on the Alps, published in 1843.

In the theory which I formerly advanced, jointly with Mr. Darwin †,

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* Archiac, Hist. des Progrès, &c. vol. ii. p. 249.

† See Elements of Geology, 2nd ed. 1841.

it was suggested that the erratics may have been transferred by floating ice to the Jura, at the time when the greater part of that chain, and the whole of the Swiss valley to the south, was under the sea. At that period the Alps may have attained only half their present altitude, and may yet have constituted a chain as lofty as the Chilian Andes, which, in a latitude corresponding to Switzerland, now send down glaciers to the head of every sound, from which icebergs, covered with blocks of granite, are floated seaward.* Opposite that part of Chili where the glaciers abound is situated the island of Chiloe, 100 miles in length, with a breadth of 30 miles, running parallel to the continent. The channel which separates it from the main land is of considerable depth, and 25 miles broad. Parts of its surface, like the adjacent coast of Chili, are overspread with recent marine shells, showing an upheaval of the land during a very modern period; and beneath these shells is a boulder deposit, in which Mr. Darwin found large travelled blocks. One group of fragments were of granite, which had evidently come from the Andes, while in another place angular blocks of syenite were met with. Their arrangement may have been due to successive crops of icebergs issuing from different sounds, to the heads of which glaciers descend from the Andes. These icebergs, taking their departure year after year from distinct points, may have been stranded repeatedly, in equally distinct groups, in bays or creeks of Chiloe, and on islets off the coast; so that the stones transported by them might hereafter appear, some on hills and others in valleys, should that country and the bed of the adjacent sea be ever upheaved. A continuance in future of the elevatory movement, in this region of the Andes and of Chiloe, might cause the former chain to rival the Alps in altitude, and give to Chiloe a height equal to that of the Jura. The same rise might dry up the channel between Chiloe and the main land, so that it would then represent the great valley of Switzerland. In the course of these changes, all parts of Chiloe and the intervening strait, having in their turn been a sea-shore, may have been polished and scratched by coast-ice, and by innumerable icebergs running aground and grating on the bottom.

If we apply this hypothesis to Switzerland and the Jura, we are by no means precluded from the supposition that, in proportion as the land acquired additional height, and the bed of the sea emerged, the Jura itself may have had its glaciers; and those existing in the Alps, which had at first extended to the sea, may, during some part of the period of upheaval, have been prolonged much farther into the valleys than now. At a later period, when the climate grew milder, these glaciers may have entirely disappeared from the Jura, and may have receded in the Alps to their present limits, leaving behind them in both districts those moraines which now attest the greater extension of the ice in former times.†

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* Darwin's Journal, p. 283.

† More recently Sir R. Murchison, having revisited the Alps, has declared his opinion that "the great granitic blocks of Mont Blanc were translated to the Jura when the intermediate country was under water." — Paper read to Geol. Soc. London, May 30. 1849.

Meteorites in drift.—Before concluding my remarks on the northern drift of the Old World, I shall refer to a fact recently announced, the discovery of a meteoric stone at a great depth in the alluvium of Northern Asia.

Erman, in his Archives of Russia for 1841 (p. 314.), cites a very circumstantial account drawn up by a Russian miner of the finding of a mass of meteoric iron in the auriferous alluvium of the Altai. Some small fragments of native iron were first met with in the gold-washings of Petropawlowsker in the Mrassker Circle; but though they attracted attention, it was supposed that they must have been broken off from the tools of the workmen. At length, at the depth of 31 feet 5 inches from the surface, they dug out a piece of iron weighing 17½ pounds, of a steel-grey colour, somewhat harder than ordinary iron, and, on analysing it, found it to consist of native iron, with a small proportion of nickel, as usual in meteoric stones. It was buried in the bottom of the deposit where the gravel rested on a flaggy limestone. Much brown iron ore, as well as gold, occurs in the same gravel, which appears to be part of that extensive auriferous formation in which the bones of the mammoth, the *Rhinoceros tichorhinus*, and other extinct quadrupeds abound. No sufficient data are supplied to enable us to determine whether it be of Post-Pliocene or Newer Pliocene date.

We ought not, I think, to feel surprise that we have not hitherto succeeded in detecting the signs of such aërolites in older rocks; for, besides their rarity in our own days, those which fell into the sea (and it is with marine strata that geologists have usually to deal), being chiefly composed of native iron, would rapidly enter into new chemical combinations, the water and mud being charged with chloride of sodium and other salts. We find that anchors, cannon, and other cast-iron implements which have been buried for a few hundred years off our English coast have decomposed in part or entirely, turning the sand and gravel which enclosed them into a conglomerate, cemented together by oxide of iron. In like manner meteoric iron, although its rusting would be somewhat checked by the alloy of nickel, could scarcely ever fail to decompose in the course of thousands of years, becoming oxide, sulphuret or carbonate of iron, and its origin being then no longer distinguishable. The greater the antiquity of rocks,—the oftener they have been heated and cooled, permeated by gases or by the waters of the sea, the atmosphere or mineral springs,—the smaller must be the chance of meeting with a mass of native iron unaltered; but the preservation of the ancient meteorite of the Altai, and the presence of nickel in these curious bodies, renders the recognition of them in deposits of remote periods less hopeless than we might have anticipated.

CHAPTER XIII.

NEWER PLIOCENE STRATA AND CAVERN DEPOSITS.

Chronological classification of Pleistocene formations, why difficult—Freshwater deposits in valley of Thames—In Norfolk cliffs—In Patagonia—Comparative longevity of species in the mammalia and testacea—Fluvio-marine crag of Norwich—Newer Pliocene strata of Sicily—Limestone of great thickness and elevation—Alternation of marine and volcanic formations—Proofs of slow accumulation—Great geographical changes in Sicily since the living fauna and flora began to exist—Osseous breccias and cavern deposits—Sicily—Kirkdale—Origin of stalactite—Australian cave-breccias—Geographical relationship of the provinces of living vertebrata and those of the fossil species of the Pliocene periods—Extinct struthious birds of New Zealand—Teeth of fossil quadrupeds.

HAVING in the last chapter treated of the boulder formation and its associated freshwater and marine strata as belonging chiefly to the close of the Newer Pliocene period, we may now proceed to other deposits of the same or nearly the same age. It should, however, be stated that it is difficult to draw the line of separation between these modern formations, especially when we are called upon to compare deposits of marine and freshwater origin, or these again with the ossiferous contents of caverns.

If as often as the carcasses of quadrupeds were buried in alluvium during floods, or mired in swamps, or imbedded in lacustrine strata, a stream of lava had descended and preserved the alluvial or freshwater deposits, as frequently happened in Auvergne (see above, p. 80.), keeping them free from intermixture with strata subsequently formed, then indeed the task of arranging chronologically the whole series of mammaliferous formations might have been easy, even though many species were common to several successive groups. But when there have been oscillations in the levels of the land, accompanied by the widening and deepening of valleys at more than one period,—when the same surface has sometimes been submerged beneath the sea, after supporting forests and land quadrupeds, and then raised again, and subject during each change of level to sedimentary deposition and partial denudation,—and when the drifting of ice by marine currents or by rivers, during an epoch of intense cold, has for a season interfered with the ordinary mode of transport, or with the geographical range of species, we cannot hope speedily to extricate ourselves from the confusion in which the classification of these Pleistocene formations is involved.

At several points in the valley of the Thames, remnants of ancient fluviatile deposits occur, which may differ considerably in age, although the imbedded land and freshwater shells in each are of recent species. At Brentford, for example, the bones of the Siberian Mammoth, or *Elephas primigenius*, and the *Rhinoceros tichorhinus*, both of them quadrupeds of which the flesh and hair have been found preserved in the frozen soil of Siberia, occur abundantly, with the bones of an hippopotamus, aurochs, short-horned ox, red deer, rein-deer, and great cave-tiger or lion.* A similar group has been found fossil at Maidstone, in Kent, and other places, agreeing in general specifically with the fossil bones detected in the caverns of England. When we see the existing rein-deer and an extinct hippopotamus in the same fluviatile loam, we are tempted to indulge our imaginations in speculating on the climatal conditions which could have enabled these genera to coexist in the same region. Wherever there is a continuity of land from polar to temperate and equatorial regions, there will always be points where the southern limit of an arctic species meets the northern range of a southern species; and if one or both have migratory habits, like the Bengal tiger, the American bison, the musk ox and others, they may each penetrate mutually far into the respective provinces of the other. There may also have been several oscillations of temperature during the periods which immediately preceded and followed the more intense cold of the glacial epoch.

The strata bordering the left bank of the Thames at Grays Thurrock, in Essex, are probably of older date than those of Brentford, although the associated land and freshwater shells are nearly all, if not all, identical with species now living. Three of the shells, however, are no longer inhabitants of Great Britain; namely, *Paludina marginata* (fig. 117. p. 133.), now living in France; *Unio littoralis* (fig. 29. p. 28.), now inhabiting the Loire; and *Cyrena consobrina* (fig. 26. p. 28.). The last-mentioned fossil (a recent Egyptian shell of the Nile) is very abundant at Grays, and deserves notice, because the genus *Cyrena* is now no longer European.

The rhinoceros occurring in the same beds (*R. leptorhinus*, see fig. 136. p. 167.) is of a different species from that of Brentford above mentioned, and the accompanying elephant belongs to the variety called *Elephas meridionalis*, which, according to MM. Owen and H. von Meyer, two high authorities, is the same species as the Siberian mammoth, although some naturalists regard it as distinct. With the above mammalia is also found the *Hippopotamus major*, and what is most remarkable in so modern and northern a deposit, a monkey, called by Owen *Macacus pliocenus*.

The submerged forest already alluded to (p. 137.) as underlying the drift at the base of the cliffs of Norfolk is associated with a bed of lignite and loam, in which a great number of fossil bones occur, apparently of the same group as that of Grays, just mentioned. It has sometimes been called "the Elephant bed." One portion of it, which stretches out under the sea at Happisburgh, was overgrown in 1820 by a bank of recent oysters, and there the fishermen dredged up, according to Woodward, in the course of thirteen years, together with the oysters, above 2000 mammoths' grinders.† Another portion

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* Morris, Geol. Soc. Proceed., 1849.

† Woodward's Geology of Norfolk.

of the same continuous stratum has yielded at Bacton, Cromer, and other places on the coast, the bones of a gigantic beaver (*Trogontherium Cuvierii*, Fischer), as well as the ox, horse, and deer, and both species of rhinoceros, *R. tichorhinus* and *R. leptorhinus.*

In studying these and various other similar assemblages of fossils, we have a good exemplification of the more rapid rate at which the mammiferous fauna, as compared to the testaceous, diverges from the recent type when traced backwards in time. I have before hinted, that the longevity of species in the class of warm-blooded quadrupeds is not so great as in that of the mollusca; the latter having probably more capacity for enduring those changes of climate and other external circumstances, and those revolutions in the organic world, which in the course of ages occur on the earth's surface. This phenomenon is by no means confined to Europe, for Mr. Darwin found at Bahia Blanca, in South America, lat 39° S., near the northern confines of Patagonia, fossil remains of the extinct mammiferous genera Megatherium, Megalonyx, Toxodon, and others, associated with shells, almost all of species already ascertained to be still living in the contiguous sea*; the marine mollusca, as well as those of rivers, lakes, or the land, having died out more slowly than the terrestrial mammalia.

I alluded before (p. 131.) to certain marine strata overlying till near Glasgow, and at other points on the Clyde, in which the shells are for the most part British, with an intermixture of some arctic species; while others, about a tenth of the whole, are supposed to be extinct. This formation may also be called Newer Pliocene.

Fluvio-marine crag of Norwich. — At several places within five miles of Norwich, on both banks of the Yare, beds of sand, loam, and gravel, provincially termed "crag," but of a very different age from the Suffolk Crag, occur, in which there is a mixture of marine, land, and freshwater shells, with ichthyolites and bones of mammalia. It is clear that these beds have been accumulated at the bottom of the sea near the mouth of a river. They form patches of variable thickness, resting on white chalk, and are covered by a dense mass of stratified flint gravel. The surface of the chalk is often perforated to the depth of several inches by the *Pholas crispata*, each fossil shell still remaining at the bottom of its cylindrical cavity, now filled up with loose sand which has fallen from the incumbent crag. This species of Pholas still exists and drills the rocks between high and low water on the British coast. The most common shells of these strata, such as *Fusus striatus*, *Turritella terebra*, *Cardium edule*, and *Cyprina islandica*, are now abundant in the British seas; but with them are some extinct species, such as *Nucula Cobboldiæ* (fig. 125.) and *Tellina obliqua* (fig. 126.). *Natica helicoides* (fig. 127.) is an example of a species formerly known only as fossil, but which has now been found living in our seas.

Among the accompanying bones of mammalia is the *Mastodon*

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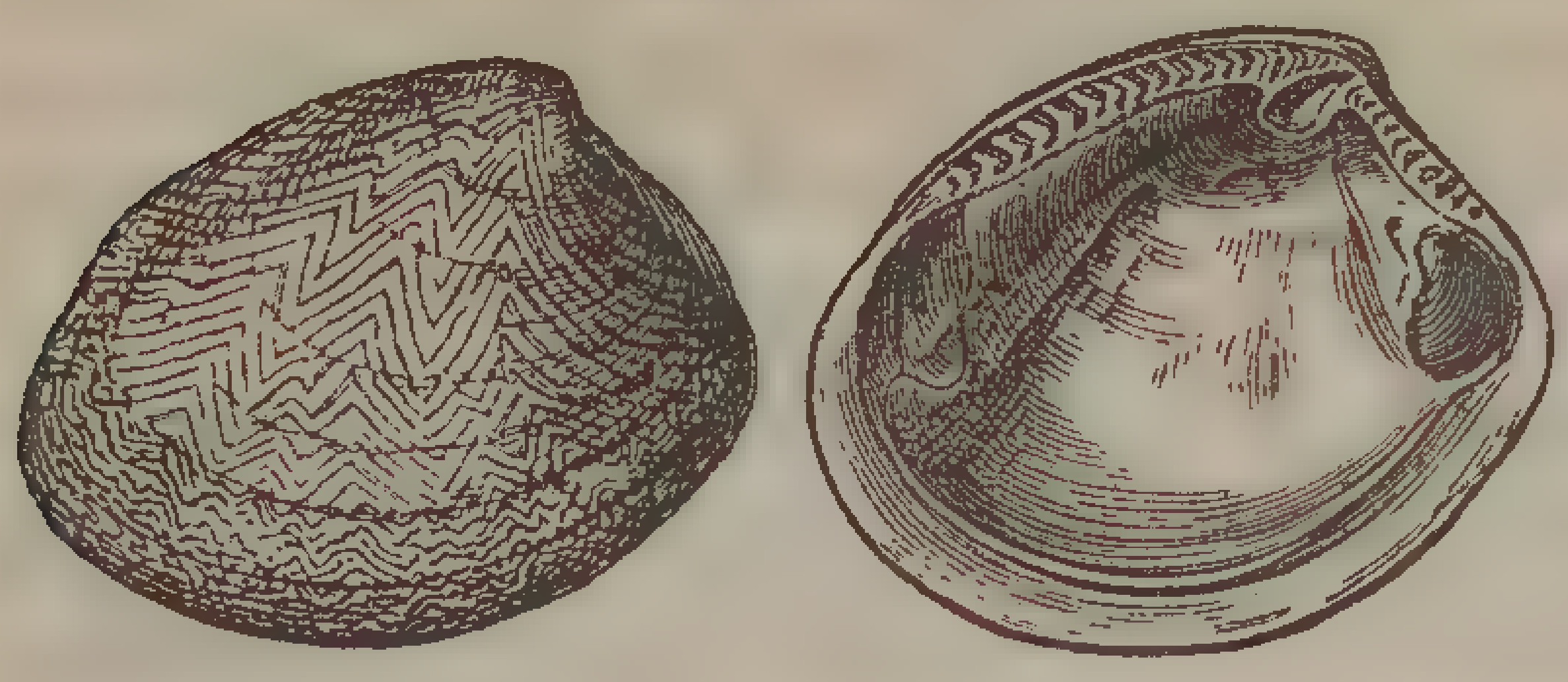
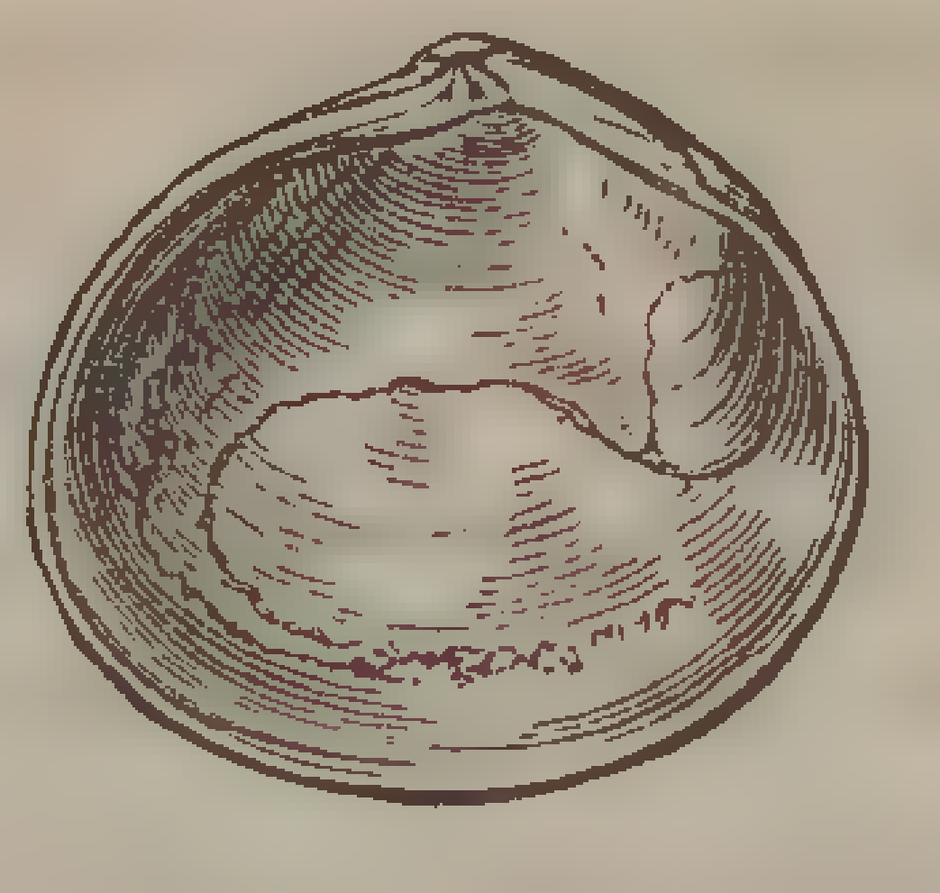
* Zool. of Beagle, part 1. pp. 9. 111.

Fig. 125.



Nucula Cobboldiæ.

Fig. 126.



Tellina obliqua.

Fig. 127.

Natica helicoides, Johnston.

*angustidens** (see fig. 135. p. 166.), a portion of the upper jawbone with a tooth having been found by Mr. Wigham at Postwick, near Norwich. As this species has also been found in the Red Crag, both at Sutton and at Felixstow, and had hitherto been regarded as characteristic of formations older than the Pleistocene, it may possibly have been washed out of the Red into the Norwich Crag.

Among the bones, however, respecting the authenticity of which there seems no doubt, may be mentioned those of the elephant, horse, pig, deer, and the jaws and teeth of field mice (fig. 146. p. 168.). I have seen the tusk of an elephant from Bramerton near Norwich, to which many serpulæ were attached, showing that it had lain for some time at the bottom of the sea of the Norwich Crag.

At Thorpe, near Aldborough, and at Southwold, in Suffolk, this fluvio-marine formation is well exposed in the sea-cliffs, consisting of sand, shingle, loam, and laminated clay. Some of the strata there bear the marks of tranquil deposition, and in one section a thickness of 40 feet is sometimes exposed to view. Some of the lamellibranchiate shells have both valves united, although mixed with land and freshwater testacea, and with the bones and teeth of elephant, rhinoceros, horse, and deer. Captain Alexander, with whom I examined these strata in 1835, showed me a bed rich in marine shells, in which he had found a large specimen of the *Fusus striatus,* filled with sand, and in the interior of which was the tooth of a horse.

Among the freshwater shells I obtained the *Cyrena consobrina* (fig. 26. p. 28.), before mentioned, supposed to agree with a species now living in the Nile.

I formerly classed the Norwich Crag as older Pliocene, conceiving that more than a third of the fossil testacea were extinct; but there now seems good reason for believing that several of the rarer shells obtained from these strata do not really belong to a contemporary fauna, but have been washed out of the older beds of the "Red Crag;" while other species, once supposed to have died out, have lately been met with living in the British seas. According to Mr. Searles Wood, the total number of marine species does not exceed seventy-six, of which one tenth only are extinct. Of the fourteen associated freshwater shells, all the species appear to be living. Strata containing the same shells as those near Norwich have been found by Mr. Bean, at Bridlington, in Yorkshire.

Newer Pliocene strata of Sicily. — In no part of Europe are the

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* Owen, Brit. Foss. Mamm. 271. *Mastodon longirostris,* Kaup, see *ibid.*

Newer Pliocene formations seen to enter so largely into the structure of the earth's crust, or to rise to such heights above the level of the sea, as in Sicily. They cover nearly half the island, and near its centre, at Castrogiovanni, they reach an elevation of 3000 feet. They consist principally of two divisions, the upper calcareous, and the lower argillaceous, both of which may be seen at Syracuse, Girgenti, and Castrogiovanni.

According to Philippi, to whom we are indebted for the best account of the tertiary shells of this island, thirty-five species out of one hundred and twenty-four obtained from the beds in central Sicily, are extinct. Of the remainder, which still live, five species are no longer inhabitants of the Mediterranean. When I visited Sicily in 1828 I estimated the proportion of living species as somewhat greater, partly because I confounded with the tertiary formation of central Sicily the strata at the base of Etna, and some other localities, where the fossils are now proved to agree entirely with the present Mediterranean fauna.

Philippi came to the conclusion, that in Sicily there is a gradual passage from beds containing 70 per cent. of recent shells, to those in which the whole of the fossils are identical with recent species; but his tables appear scarcely to bear out so important a generalization, several of the places cited by him in confirmation having as yet furnished no more than twenty or thirty species of testacea. The Sicilian beds in question probably belong to about the same period as the Norwich Crag, although a geologist, accustomed to see nearly all the Pleistocene formations in the north of Europe occupying low grounds and very incoherent in texture, is naturally surprised to behold formations of the same age so solid and stony, of such thickness, and attaining so great an elevation above the level of the sea.

The upper or calcareous member of this group in Sicily consists in some places of a yellowish-white stone, like the calcaire grossier of Paris; in others, of a rock nearly as compact as marble. Its aggregate thickness amounts sometimes to 700 or 800 feet. It usually occurs in regular horizontal beds, and is occasionally intersected by deep valleys, such as those of Sortino and Pentalica, in which are numerous caverns. The fossils are in every stage of preservation, from shells retaining portions of their animal matter and colour, to others which are mere casts.

The limestone passes downwards into a sandstone and conglomerate, below which is clay and blue marl, like that of the Subapennine hills, from which perfect shells and corals may be disengaged. The clay sometimes alternates with yellow sand.

South of the plain of Catania is a region in which the tertiary beds are intermixed with volcanic matter, which has been for the most part the product of submarine eruptions. It appears that, while the clay, sand, and yellow limestone before mentioned were in course of deposition at the bottom of the sea, volcanos burst out beneath the waters, like that of Graham Island, in 1831, and these explosions recurred again and again at distant intervals of time. Volcanic ashes and sand were showered down and spread by the waves and currents so as to form strata of tuff, which are found intercalated between beds of limestone and clay containing marine shells, the thickness of the whole mass exceeding 2000 feet. The fissures through which the lava rose may be seen in many places forming what are called *dikes.* In part of the region above alluded to, as, for example, near Lentini, a conglomerate occurs in which I observed many pebbles of volcanic rocks covered by full-grown *serpulæ.* We may explain the origin of these by supposing that there were some small volcanic islands which may have been destroyed from time to time by the waves, as Graham Island has been swept away since 1831. The rounded blocks and pebbles of solid volcanic matter, after being rolled for a time on the beach of such temporary islands, were carried at length into some tranquil part of the sea, where they lay for years, while the marine *serpulæ* adhered to them, their shells growing and covering their surface, as they are seen adhering to the shell figured in p. 22. Finally, the bed of pebbles was itself covered with strata of shelly limestone. At Vizzini, a town not many miles distant to the S. W., I remarked another striking proof of the gradual manner in which these modern rocks were formed, and the long intervals of time which elapsed between the pouring out of distinct sheets of lava, a bed of oysters no less than 20 feet in thickness rests upon a current of basaltic lava. The oysters are perfectly identifiable with our common eatable species. Upon the oyster bed, again, is superimposed a second mass of lava, together with tuff or peperino. In the midst of the same alternating igneous and aqueous formations is seen near Galieri, not far from Vizzini, a horizontal bed, about a foot and a half in thickness, composed entirely of a common Mediterranean coral (*Caryophyllia cæspitosa,* Lam.). These corals stand erect as they grew; and, after being traced for hundreds of yards, are again found at a corresponding height on the opposite side of the valley.

Fig. 128.

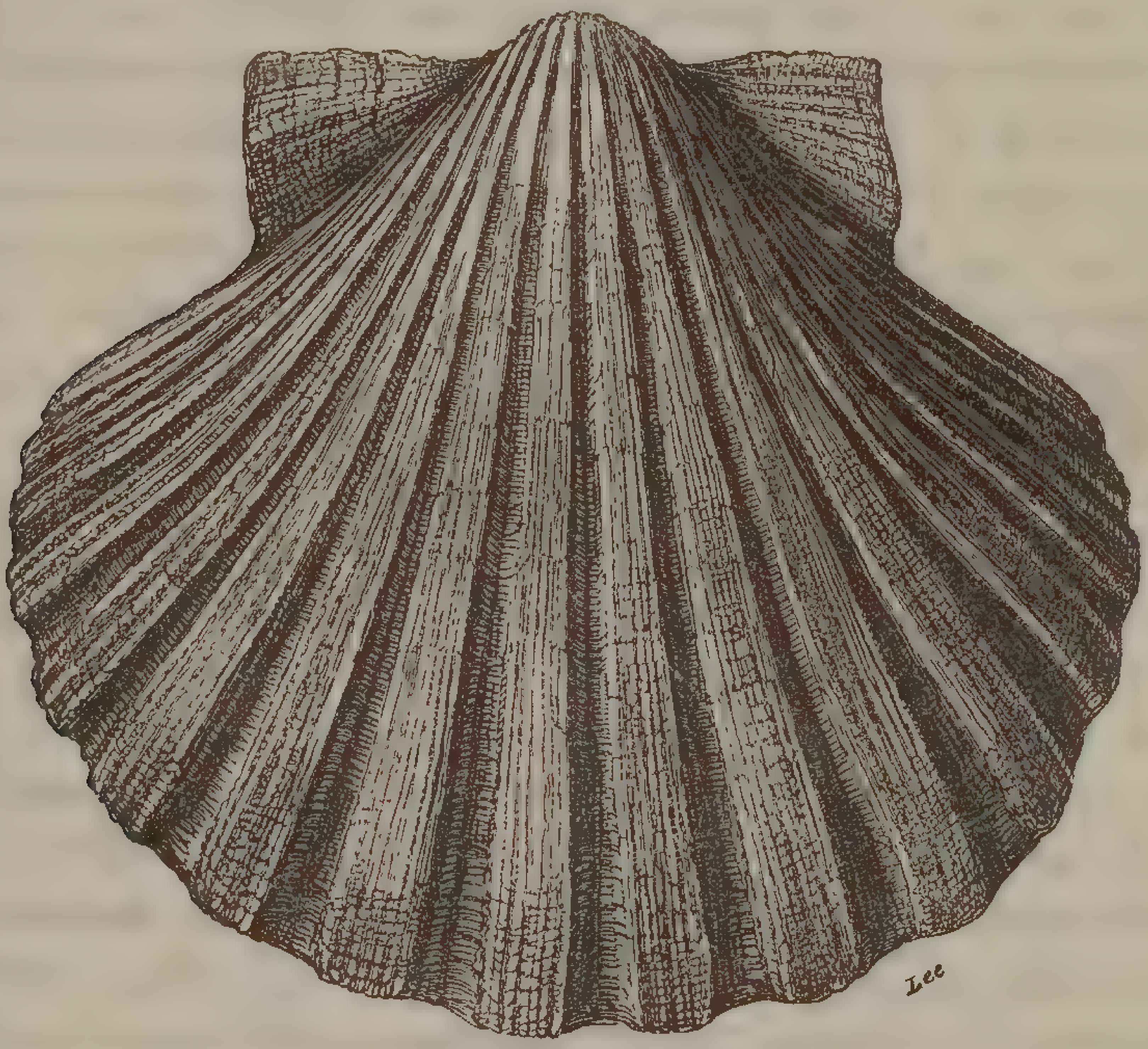
Caryophyllia cæspitosa, Lam. (*Cladocora stellaria,* Milne Edw. and Haime.)

a. Stem with young stem growing from its side.
a.* Young stem of same twice magnified.
b. Portion of branch, twice magnified, with the base of a lateral branch; the exterior ridges of the main branch appearing through the lamellæ of the lateral one.
c. Transverse section of same, proving, by the integrity of the main branch, that the lateral one did not originate in a subdivision of the animal.
d. A branch, having at its base another laterally united to it, and two young corals at its upper part.
e. A main branch, with a full-grown lateral one.
f. A perfect terminal star.

The corals are usually branched, but not by the division of the animals as some have supposed, but by the attachment of young individuals to the sides of the older ones; and we must understand this mode of increase, in order to appreciate the time which was required for the building up of the whole bed of coral during the growth of many successive generations.*

Among the other fossil shells met with in these Sicilian strata, which still continue to abound in the Mediterranean, no shell is more conspicuous, from its size and frequent occurrence, than the great scallop, *Pecten jacobæus* (see fig. 129.), now so common in the neighbouring seas. We see this shell in the calcareous beds at Palermo in great numbers, in the limestone at Girgenti, and in that which alternates with volcanic rocks in the country between Syracuse and Vizzini, often at great heights above the sea.

Fig. 129.



Pecten jacobæus; half natural size.

The more we reflect on the preponderating number of these recent shells, the more we are surprised at the great thickness, solidity, and height above the sea of the rocky masses in which they are entombed, and the vast amount of geographical change which has taken place since their origin. It must be remembered that, before they began to emerge, the uppermost strata of the whole must have been deposited under water. In order, therefore, to form a just conception of their antiquity, we must first examine singly the innumerable minute parts of which the whole is made up, the successive beds of shells, corals, volcanic ashes, conglomerates, and sheets of lava; and we must afterwards contemplate the time required for the gradual upheaval of the rocks, and the excavation of the valleys. The historical period seems scarcely to form an appreciable unit in this com-

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* I am indebted to Mr. Lonsdale for the details above given respecting the structure of this coral.

putation, for we find ancient Greek temples, like those of Girgenti (Agrigentum), built of the modern limestone of which we are speaking, and resting on a hill composed of the same; the site having remained to all appearance unaltered since the Greeks first colonised the island.

The modern geological date of the rocks in this region leads to another singular and unexpected conclusion — namely, that the fauna and flora of a large part of Sicily are of higher antiquity than the country itself, having not only flourished before the lands were raised from the deep, but even before their materials were brought together beneath the waters. The chain of reasoning which conducts us to this opinion may be stated in a few words. The larger part of the island has been converted from sea into land since the Mediterranean was peopled with nearly all the living species of testacea and zoophytes. We may therefore presume that, before this region emerged, the same land and river shells, and almost all the same animals and plants, were in existence which now people Sicily; for the terrestrial fauna and flora of this island are precisely the same as that of other lands surrounding the Mediterranean. There appear to be no peculiar or indigenous species, and those which are now established there must be supposed to have migrated from pre-existing lands, just as the plants and animals of the Neapolitan territory have colonized Monte Nuovo, since that volcanic cone was thrown up in the sixteenth century.

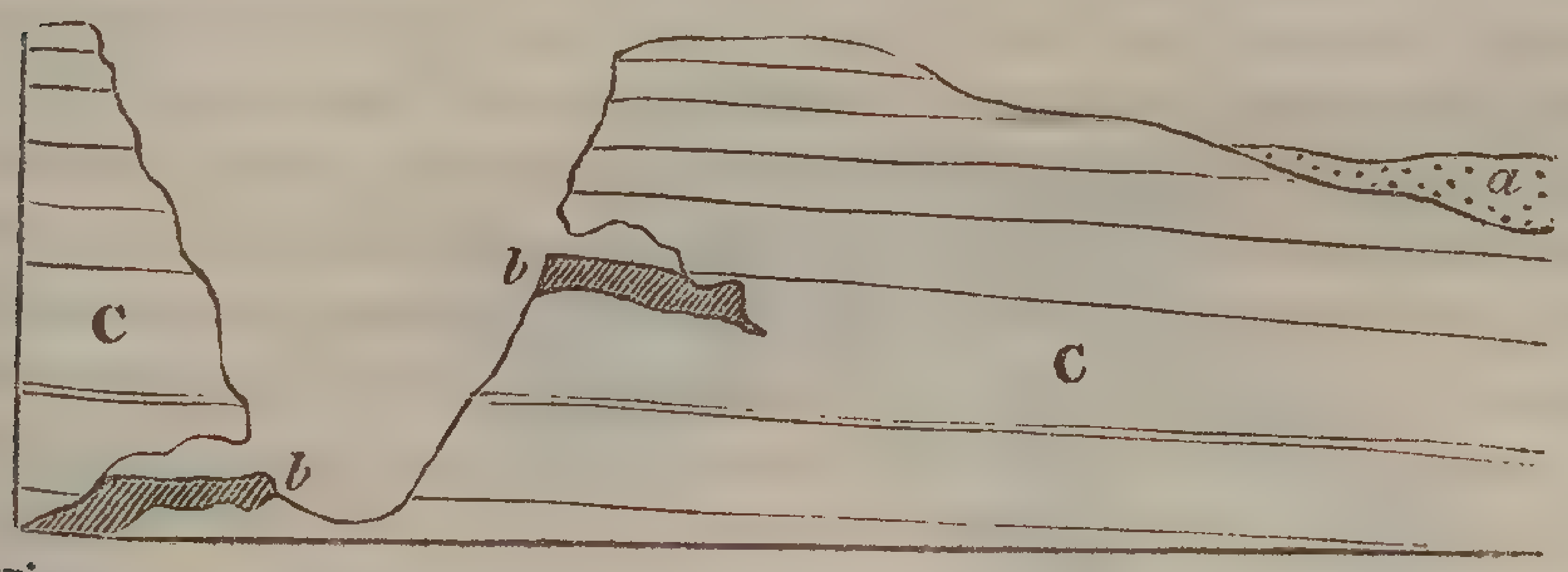
Such conclusions throw a new light on the adaptation of the attributes and migratory habits of animals and plants to the changes which are unceasingly in progress in the physical geography of the globe. It is clear that the duration of species is so great, that they are destined to outlive many important revolutions in the configuration of the earth's surface; and hence those innumerable contrivances for enabling the subjects of the animal and vegetable creation to extend their range; the inhabitants of the land being often carried across the ocean, and the aquatic tribes over great continental species. It is obviously expedient that the terrestrial and fluviatile species should not only be fitted for the rivers, valleys, plains, and mountains which exist at the era of their creation, but for others that are destined to be formed before the species shall become extinct; and, in like manner, the marine species are not only made for the deep and shallow regions of the ocean existing at the time when they are called into being, but for tracts that may be submerged or variously altered in depth during the time that is allotted for their continuance on the globe.

OSSEOUS BRECCIAS AND DEPOSITS IN CAVES OF THE PLIOCENE PERIOD.

Sicily. — Caverns filled with marine breccias, at the base of ancient sea-cliffs, have been already mentioned in the sixth chapter; and it was noticed, respecting the cave of San Ciro, near Palermo (p. 75.), that upon a bed of sand filled with sea-shells, almost all of recent species, rests a breccia (*b*, fig. 93. p. 75.), composed of fragments of calcareous rock, and the bones of animals. In the sand at the bottom of that cave, Dr. Philippi found about forty-five marine shells, all clearly identical with recent species, except two or three. The bones in the incumbent breccia are chiefly those of the mammoth (*E. primigenius*), with some belonging to an hippopotamus, distinct from the recent species, and smaller than that usually found fossil. (See fig. 137. p. 167.) Several species of deer also, and, according to some accounts, the remains of a bear, were discovered. These mammalia are probably referable to the Post-Pliocene period.

The Newer Pliocene tertiary limestone of the south of Sicily, already described, is sometimes full of caverns; and the student will at once perceive that all the quadrupeds of which the remains are found in the stalactite of these caverns, being of later origin than the rocks, must be referable to the close of the tertiary epoch, if not of still later date. The situation of one of these caves, in the valley of Sortino, is represented in the annexed section.

Fig. 130.



a. Alluvium,
b, *b*. Deposits in caves, } containing the remains of quadrupeds for the most part extinct.
C. Limestone, containing the remains of shells, of which between 70 and 80 per cent. are recent.

England.—In the cave at Kirkdale, about twenty-five miles N.N.E. of York, the remains of about 300 hyænas, belonging to individuals of every age, have been detected. The species (*Hyæna spelæa*) is extinct, and was larger than the fierce *Hyæna crocuta* of South Africa, which it most resembled. Dr. Buckland, after carefully examining the spot, proved that the Hyænas must have lived there; a fact attested by the quantity of their dung, which, as in the case of the living hyæna, is of nearly the same composition as bone, and almost as durable. In the cave were found the remains of the ox, young elephant, hippopotamus, rhinoceros, horse, bear, wolf, hare, water-rat, and several birds. All the bones have the appearance of having been broken and gnawed by the teeth of the hyænas; and they occur confusedly mixed in loam or mud, or dispersed through a crust of stalagmite which covers it. In these and many other cases it is supposed that portions of herbivorous quadrupeds have been dragged into caverns by beasts of prey, and have served as their food, an opinion quite consistent with the known habits of the living hyæna.

No less than thirty-seven species of mammalia are enumerated by Professor Owen as having been discovered in the caves of the British islands, of which eighteen appear to be extinct, while the others still survive in Europe. They were not washed to the spots where the fossils now occur by a great flood; but lived and died, one generation after another, in the places where they lie buried. Among other arguments in favour of this conclusion may be mentioned the great numbers of the shed antlers of deer discovered in caves and in freshwater strata throughout England.*

Examples also occur of fissures into which animals have fallen from time to time, or have been washed in from above, together with alluvial matter and fragments of rock detached by frost, forming a mass which may be united into a bony breccia by stalagmitic infiltrations. Frequently we discover a long suite of caverns connected by narrow and irregular galleries, which hold a tortuous course through the interior of mountains, and seem to have served as the subterranean channels of springs and engulphed rivers. Many streams in the Morea are now carrying bones, pebbles, and mud into underground passages of this kind. If, at some future period, the form of that country should be wholly altered by subterranean movements and new valleys shaped out by denudation, many portions of the former channels of these engulphed streams may communicate with the surface, and become the dens of wild beasts, or the recesses to which quadrupeds retreat to die. Certain caves of France, Germany, and Belgium may have passed successively through these different conditions, and in their last state may have remained open to the day for several tertiary periods. It is nevertheless very remarkable, that on the continent of Europe, as in England, the fossil remains of mammalia belong almost exclusively to those of the Newer Pliocene and Post-Pliocene periods, and not to the Miocene or Eocene epochs, and when they are accompanied by land or river shells, these agree in great part, or entirely, with recent species.

As the preservation of the fossil bones is due to a slow and constant supply of stalactite, brought into the caverns by water dropping from the roof, the source and origin of this deposit has been a subject of curious inquiry. The following explanation of the phenomenon has been recently suggested by the eminent chemist Liebig. On the surface of Franconia, where the limestone abounds in caverns, is a fertile soil, in which vegetable matter is continually decaying. This mould or humus, being acted on by moisture and air, evolves carbonic acid, which is dissolved by rain. The rain water, thus impregnated, permeates the porous limestone, dissolves a portion of it, and afterwards, when the excess of carbonic acid evaporates in the caverns, parts with the calcareous matter, and forms stalactite. Such facts seem to imply that the date of the emergence of the district was very modern, for stalactite could not begin to form until the emergence of the cavernous rock, and the land shells and land animals are usually imbedded in the lowest part of the stalactitic deposit.

Australian cave-breccias.— Ossiferous breccias are not confined to Europe, but occur in all parts of the globe; and those lately dis-

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* Owen, Brit. Foss. Mam. xxvi., and Buckland, Rel. Dil. 19. 24.

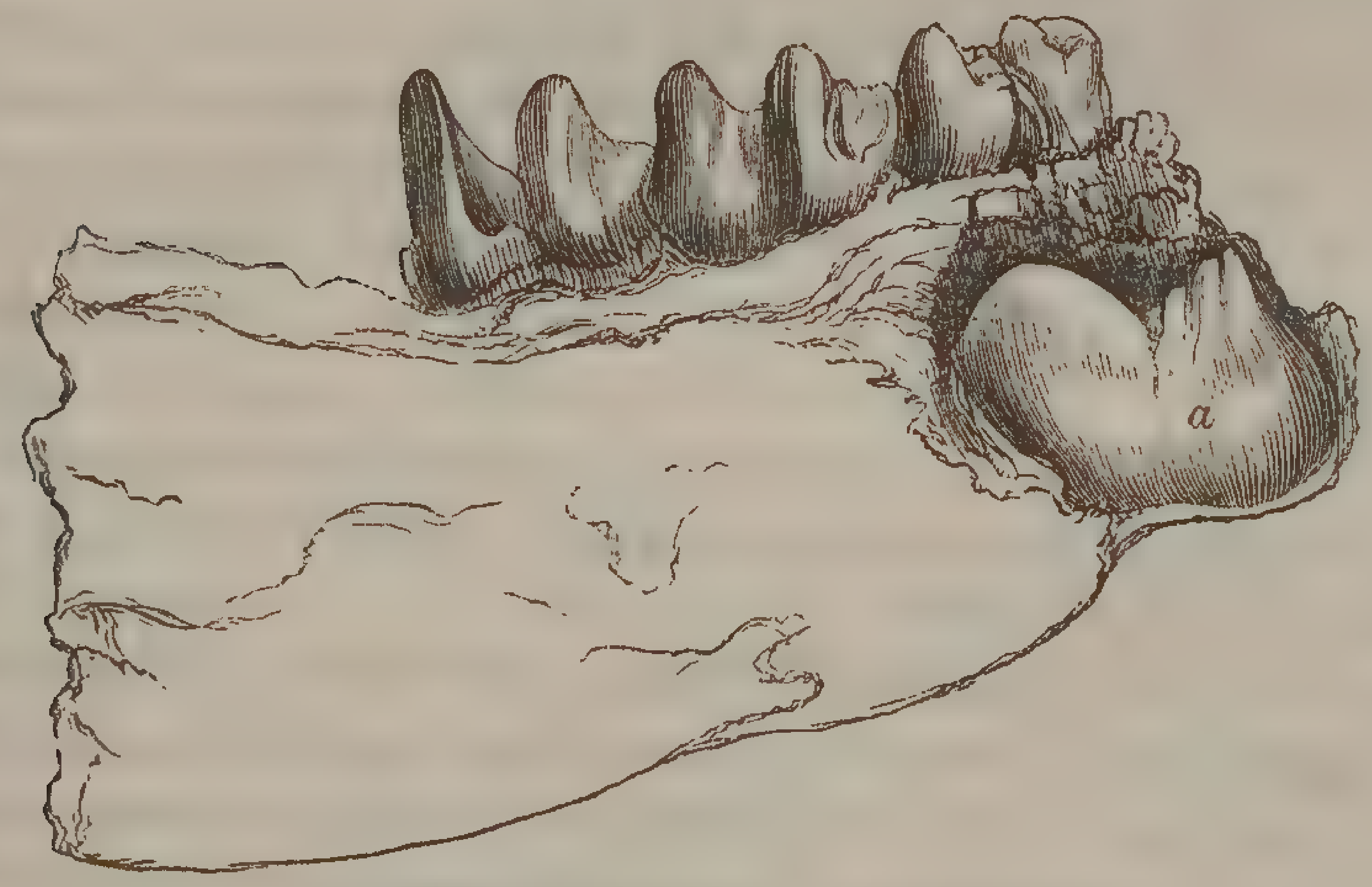
covered in fissures and caverns in Australia correspond closely in character with what has been called the bony breccia of the Mediterranean, in which the fragments of bone and rock are firmly bound together by a red ochreous cement.

Some of these caves have been examined by Sir T. Mitchell in the Wellington Valley, about 210 miles west of Sidney, on the river Bell, one of the principal sources of the Macquarie, and on the Macquarie itself. The caverns often branch off in different directions through the rock, widening and contracting their dimensions, and the roofs and floors are covered with stalactite. The bones are often broken, but do not seem to be water-worn. In some places they lie imbedded in loose earth, but they are usually included in a breccia.

The remains found most abundantly are those of the kangaroo, ot which there are four species, besides which the genera *Hypsiprymnus*, *Phalangista*, *Phascolomys*, and *Dasyurus*, occur. There are also bones, formerly conjectured by some osteologists to belong to the hippopotamus, and by others to the dugong, but which are now referred by Mr. Owen to a marsupial genus, allied to the *Wombat*.

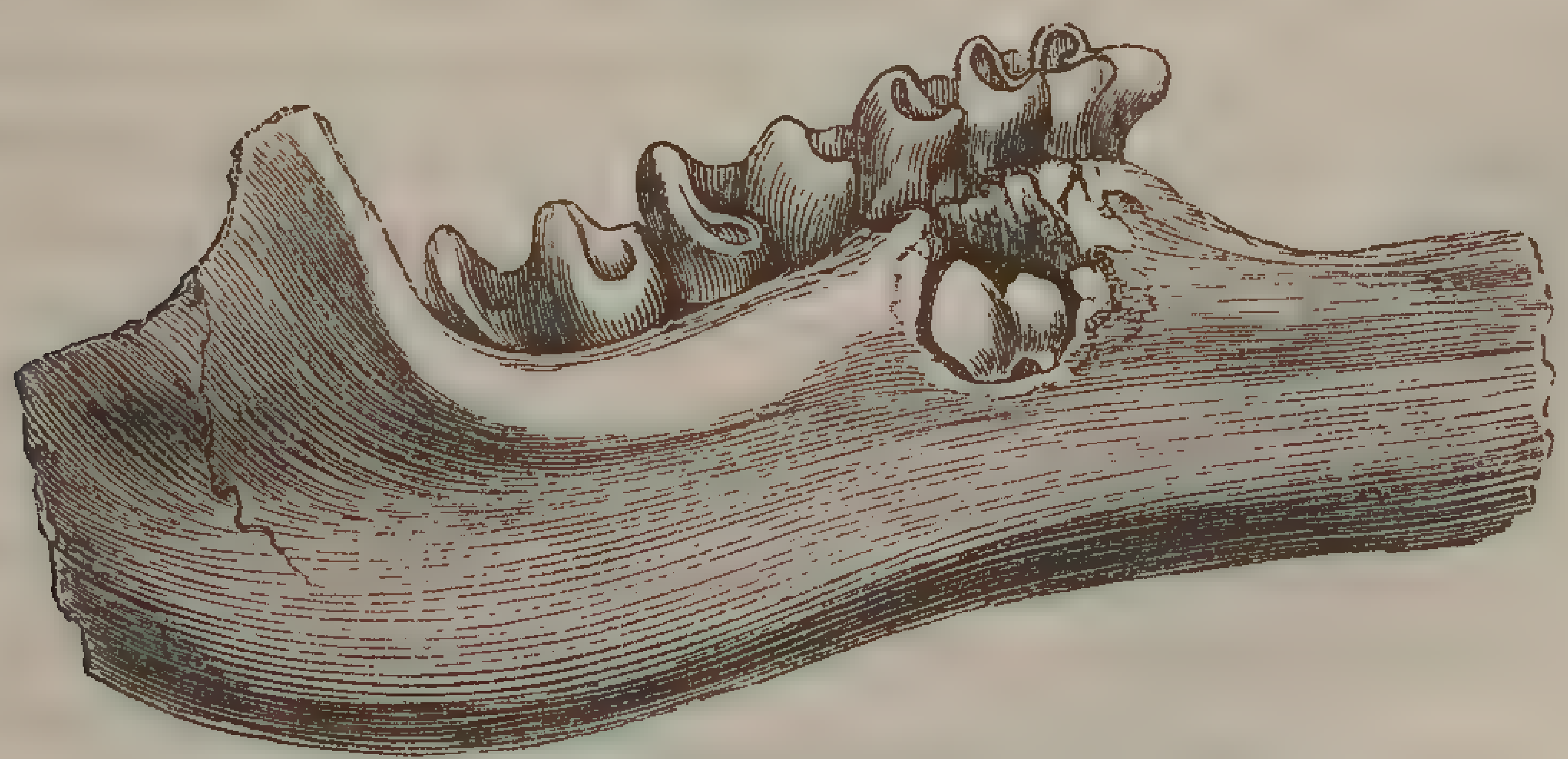
In the fossils above enumerated, several species are larger than the largest living ones of the same genera now known in Australia. The preceding figure of the right side of a lower jaw of a kangaroo

Fig. 131.



Macropus atlas, Owen.
a. permanent false molar, in the alveolus.

Fig. 132.



Lowest jaw of largest living species of kangaroo.
(*Macropus major*.)

(*Macropus atlas*, Owen) will at once be seen to exceed in magnitude the corresponding part of the largest living kangaroo, which is represented in fig. 132. In both these specimens part of the substance of the jaw has been broken open, so as to show the permanent false molar (*a.* fig. 131.) concealed in the socket. From the fact of this molar not having been cut, we learn that the individual was young, and had not shed its first teeth. In fig. 133. a front tooth of the same species of kangaroo is represented.

Fig. 133.

Incisor of *Macropus.*

Whether the breccias, above alluded to, of the Wellington Valley, appertain strictly to the Pliocene period cannot be affirmed with certainty, until we are more thoroughly acquainted with the recent quadrupeds of the same district, and until we learn what species of fossil land-shells, if any, are buried in the deposits of the same caves.

The reader will observe that all these extinct quadrupeds of Australia belong to the marsupial family, or, in other words, that they are referable to the same peculiar type of organization which now distinguishes the Australian mammalia from those of other parts of the globe. This fact is one of many pointing to a general law deducible from the fossil vertebrate and invertebrate animals of the eras immediately antecedent to the human, namely, that the present geographical distribution of organic *forms* dates back to a period anterior to the creation of existing *species;* in other words, the limitation of particular genera or families of quadrupeds, mollusca, &c., to certain existing provinces of land and sea, began before the species now contemporary with man had been introduced into the earth.

Mr. Owen, in his excellent "History of British Fossil Mammals," has called attention to this law, remarking that the fossil quadrupeds of Europe and Asia differ from those of Australia or South America. We do not find, for example, in the Europæo-Asiatic province fossil kangaroos or armadillos, but the elephant, rhinoceros, horse, bear, hyæna, beaver, hare, mole, and others, which still characterize the same continent.

In like manner, in the Pampas of South America the skeletons of Megatherium, Megalonyx, Glyptodon, Mylodon, Toxodon, Macrauchenia, and other extinct forms, are analogous to the living sloth, armadillo, cavy, capybara, and llama. The fossil quadrumana, also associated with some of these forms in the Brazilian caves, belong to the Platyrrhine family of monkeys, now peculiar to South America. That the extinct fauna of Buenos Ayres and Brazil was very modern has been shown by its relation to deposits of marine shells, agreeing with those now inhabiting the Atlantic; and when in Georgia in 1845, I ascertained that the Megatherium, Mylodon, *Harlanus americanus* (Owen), *Equus curvidens,* and other quadrupeds allied to the Pampean type, were posterior in date to beds containing marine shells belonging to forty-five recent species of the neighbouring sea.

There are indeed some cosmopolite genera, such as the Mastodon (a genus of the elephant family) and the horse, which were simultaneously represented by different fossil species in Europe, North America, and South America; but these few exceptions can by no means invalidate the rule which has been thus expressed by Professor Owen, that in "the highest organized class of animals the same forms were restricted to the same great provinces at the Pliocene periods as they are at the present day."

However modern, in a geological point of view, we may consider the Pleistocene epoch, it is evident that causes more general and powerful than the intervention of man have occasioned the disappearance of the ancient fauna from so many extensive regions. Not a few of the species had a wide range; the same Megatherium, for instance, extended from Patagonia and the river Plata in South America, between latitudes 31° and 39° south, to corresponding latitudes in North America, the same animal being also an inhabitant of the intermediate country of Brazil, where its fossil remains have been met with in caves. The extinct elephant, likewise, of Georgia (*Elephas primigenius*) has been traced in a fossil state northward from the river Alatamaha, in lat. 33° 50′ N. to the polar regions, and then again in the eastern hemisphere from Siberia to the south of Europe. If it be objected that, notwithstanding the adaptation of such quadrupeds to a variety of climates and geographical conditions, their great size exposed them to extermination by the first hunter tribes, we may observe that the investigations of Lund and Clausen in the ossiferous limestone caves of Brazil have demonstrated that these large mammalia were associated with a great many smaller quadrupeds, some of them as diminutive as field mice, which have all died out together, while the land-shells formerly their contemporaries still continue to exist in the same countries. As we may feel assured that these minute quadrupeds could never have been extirpated by man, especially in a country so thinly peopled as Brazil, so we may conclude that all the species, small and great, have been annihilated one after the other, in the course of indefinite ages, by those changes of circumstances in the organic and inorganic world which are always in progress, and are capable in the course of time of greatly modifying the physical geography, climate, and all other conditions on which the continuance upon the earth of any living being must depend.*

The law of geographical relationship above alluded to, between the living vertebrata of every great zoological province and the fossils of the period immediately antecedent, even where the fossil species are extinct, is by no means confined to the mammalia. New Zealand, when first examined by Europeans, was found to contain no indigenous land quadrupeds, no kangaroos, or opossums, like Australia; but a wingless bird abounded there, the smallest living representative of the ostrich family, called the Xivi, by the natives (*Apteryx*). In

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* See Principles of Geology, chaps. xli. to xliv.

the fossils of the Post-Pliocene and Pleistocene period in this same island, there is the like absence of kangaroos, opossums, wombats, and the rest; but in their place a prodigious number of well preserved specimens of gigantic birds of the struthious order, called by Owen *Dinornis* and *Palapteryx*, which are entombed in superficial deposits. These genera comprehended many species, some of which were 4, some 7, others 9, and others 11 feet in height! It seems doubtful whether any contemporary mammalia shared the land with this population of gigantic feathered bipeds.

To those who have never studied comparative anatomy it may seem scarcely credible, that a single bone taken from any part of the skeleton may enable a skilful osteologist to distinguish, in many cases, the genus, and sometimes the species, of quadruped to which it belonged. Although few geologists can aspire to such knowledge, which must be the result of long practice and study, they will nevertheless derive great advantage from learning, what is comparatively an easy task, to distinguish the principal divisions of the mammalia by the forms and characters of their teeth. The annexed figures, all taken from original

Fig. 134.

Elephas primigenius (or Mammoth); molar of upper jaw, right side; one third of nat. size.
a. grinding surface. *b*. side view.

Fig. 135.

Mastodon angustidens (Norwich Crag, Postwick, also found in Red Crag, see p. 156.); second true molar, left side, upper jaw; grinding surface, nat. size. (See p. 156.)

specimens, may be useful in assisting the student to recognize the teeth of many genera most frequently found fossil in the Newer Pliocene and Post-Pliocene periods.

Fig. 136.

Rhinoceros.

Rhinoceros leptorhinus; fossil from freshwater beds of Grays, Essex (see p. 154.): penultimate molar, lower jaw, left side; two-thirds of nat. size.

Fig. 137.

Hippopotamus.

Hippopotamus; from cave near Palermo (see p. 160.); molar tooth; two-thirds of nat. size.

Fig. 138.

Pig.

Sus scrofa, Lin. (common pig); from shell-marl, Forfarshire; posterior molar, lower jaw, nat. size.

Fig. 139.

Horse.

Equus caballus, Lin. (common horse); from the shell-marl, Forfarshire; second molar, lower jaw.

a. grinding surface, two-thirds nat. size.
b. side view of same, half nat. size.

Fig. 140.

Tapir.

Tapirus Americanus; recent; third molar, upper jaw; nat. size.

Fig. 141.

a. b. Deer.

Elk (*Cervus alces,* Lin.); recent; molar of upper jaw.

a. grinding surface.
b. side view; two-thirds of nat. size.

Fig. 142.

c. d. Ox.

Ox, common, from shell-marl, Forfarshire; true molar, upper jaw; two-thirds nat. size.

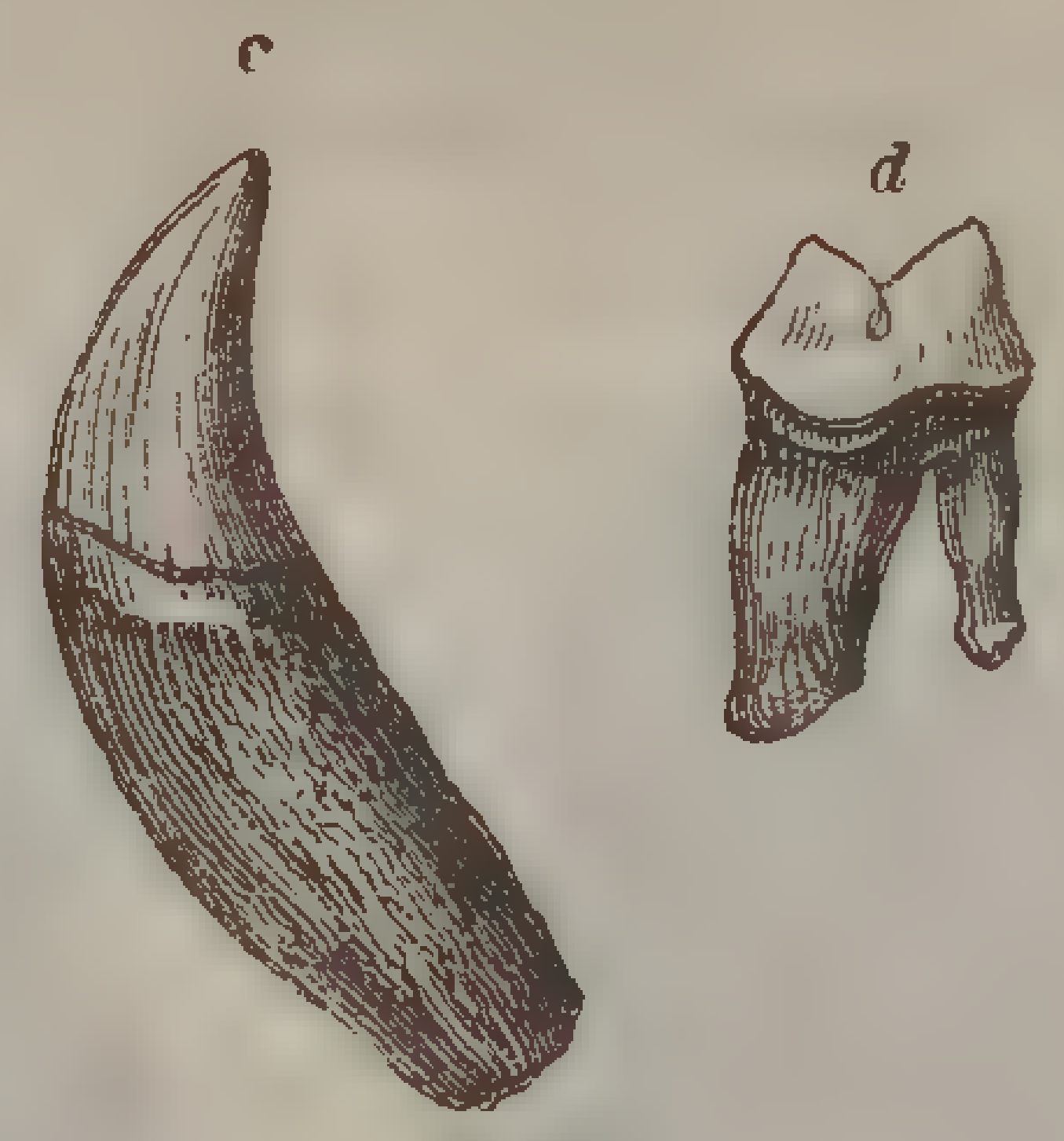
c. grinding surface.
d. side view; fangs uppermost.

Fig. 143.

Bear.

a. canine tooth or tusk of bear (*Ursus spelæus*); from cave near Liege.
b. molar of left side, upper jaw; one-third of nat. size.

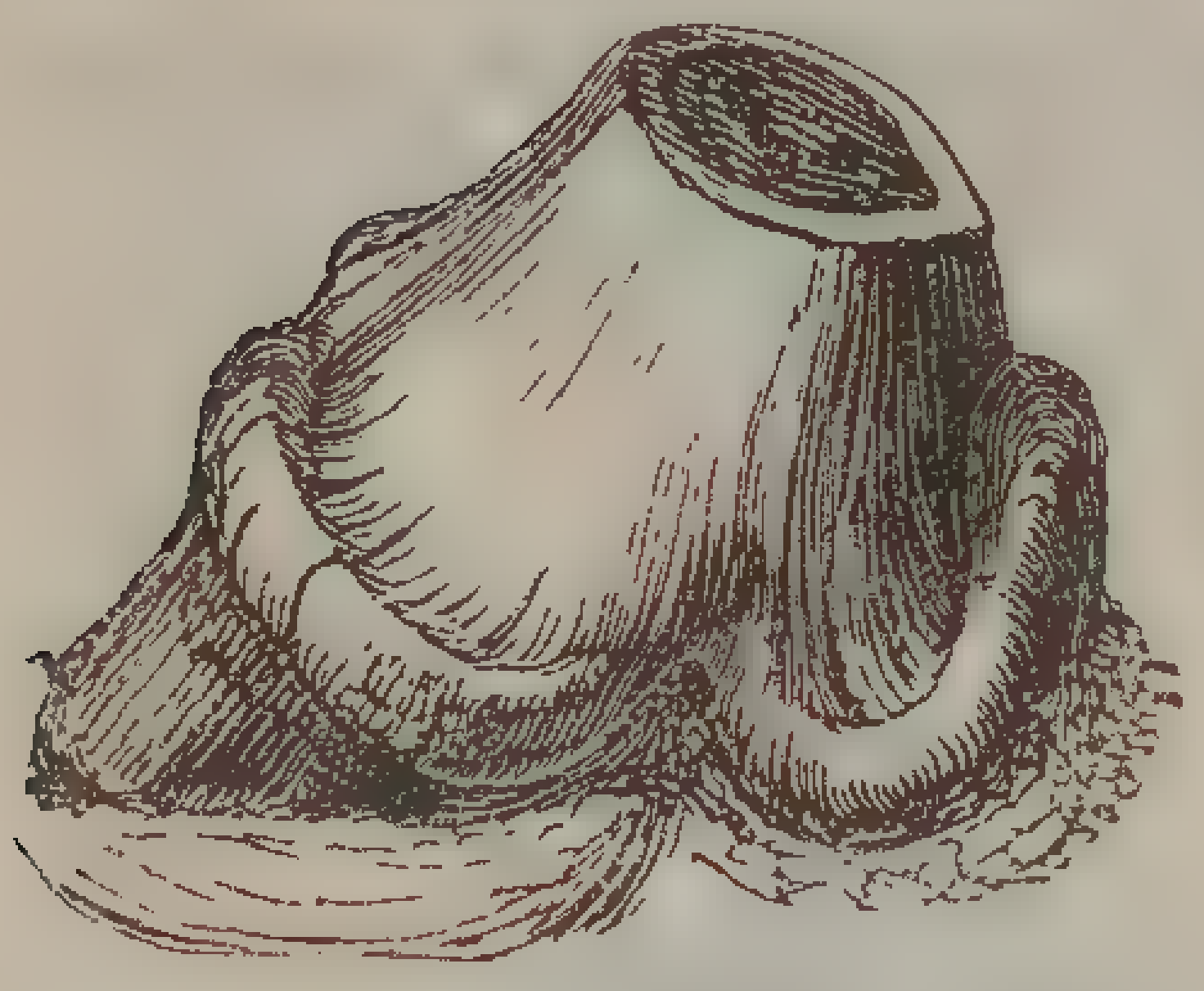
Fig. 144.



Tiger.

c. canine tooth of tiger (*Felis tigris*); recent.
d. outside view of posterior molar, lower jaw; one-third of nat. size.

Fig. 145.



Hyæna spelæa; second molar, left side, lower jaw; nat. size. Cave of Kirkdale. (See p. 161.

Fig. 146.

Teeth of a new species of *Arvicola* (field-mouse); from the Norwich Crag. (See p. 163.)
a. grinding surface. *b.* side view of same.
c. nat. size of *a* and *b.*

Fig. 147.

a. fourth molar, right side, lower jaw. *Megatherium;* Georgia, U. S.; one-third nat. size. *b.* crown of same.

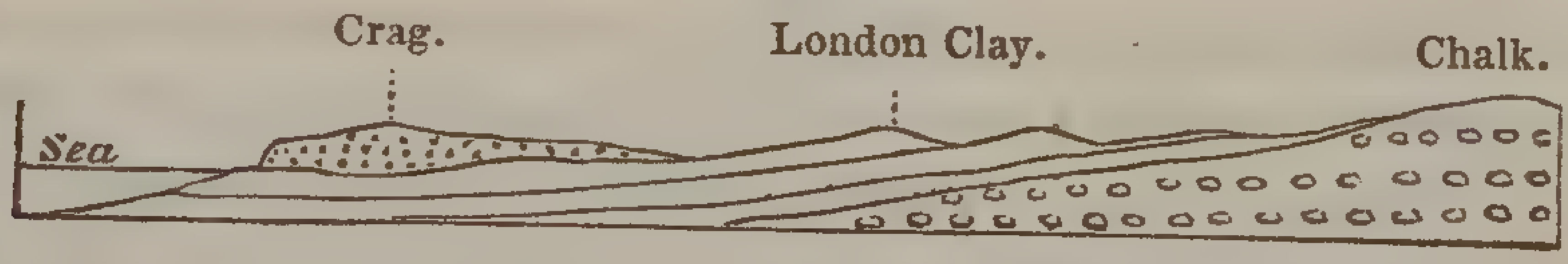
CHAPTER XIV.

OLDER PLIOCENE AND MIOCENE FORMATIONS.

Strata of Suffolk termed Red and Coralline Crag—Fossils, and proportion of recent species—Depth of sea and climate—Reference of Suffolk Crag to the Older Pliocene period—Migration of many species of shells southwards during the glacial period—Fossil whales—Antwerp Crag—Subapennine beds—Asti, Sienna, Rome—Aralo-Caspian formations—Miocene formations—Faluns of Touraine—Depth of sea and littoral character of fauna—Tropical climate implied by the testacea—Proportion of recent species of shells—Faluns more ancient than the Suffolk Crag—Miocene strata of Bordeaux—of the Bolderberg in Belgium—of North Germany—Vienna Basin—Piedmont—Molasse of Switzerland—Leaf-beds of Mull in Scotland—Older Pliocene and Miocene formations in the United States—Sewâlik Hills in India.

THE older Pliocene strata, which next claim our attention, are chiefly confined, in Great Britain, to the eastern part of the county of Suffolk, where, like the Norwich beds already described, they are called "Crag," a provincial name given particularly to those masses of shelly sand which have been used from very ancient times in agriculture, to fertilize soils deficient in calcareous matter. The relative position of the "Red Crag" in Essex to the London clay, may be understood by reference to the accompanying diagram (fig. 148.).

Fig. 148.



These deposits, according to Professor E. Forbes, appear by their imbedded shells to have been formed in a sea of moderate depth, usually from 15 to 25 fathoms, but in some few spots perhaps deeper. Yet they cannot be called littoral, because the fauna is such as may have extended 40 or 50 miles from land.

The Suffolk Crag is divisible into two masses, the upper of which has been termed the Red, and the lower the Coralline Crag.* The upper deposit consists chiefly of quartzose sand, with an occasional intermixture of shells, for the most part rolled, and sometimes comminuted. In many places fossils washed out of older tertiary strata, especially the London Clay, are met with. The lower or coralline Crag is of very limited extent, ranging over an area about 20 miles in length, and 3 or 4 in breadth, between the rivers Alde and Stour. It is generally calcareous and marly—a mass of shells, bryozoa †, and small corals, passing occasionally into a soft building stone. At Sudbourn, near Orford, where it assumes this character, are large quarries, in which the bottom of it has not been reached at the depth of 50 feet. At some places in the neighbourhood, the softer mass is divided by thin flags of hard limestone, and corals placed in the upright position in which they grew.

The Red Crag is distinguished by the deep ferruginous or ochreous colour of its sands and fossils, the Coralline by its white colour. Both formations are of moderate thickness; the Red Crag rarely exceeding 40, and the Coralline seldom amounting to 20, feet. But their importance is not to be estimated by the density of the mass of strata or its geographical extent, but by the extraordinary richness of its organic remains, belonging to a very peculiar type, which seems to characterize the state of the living creation in the north of Europe during the Older Pliocene era.

For a large collection of the fish, echinoderms, shells, bryozoa, and

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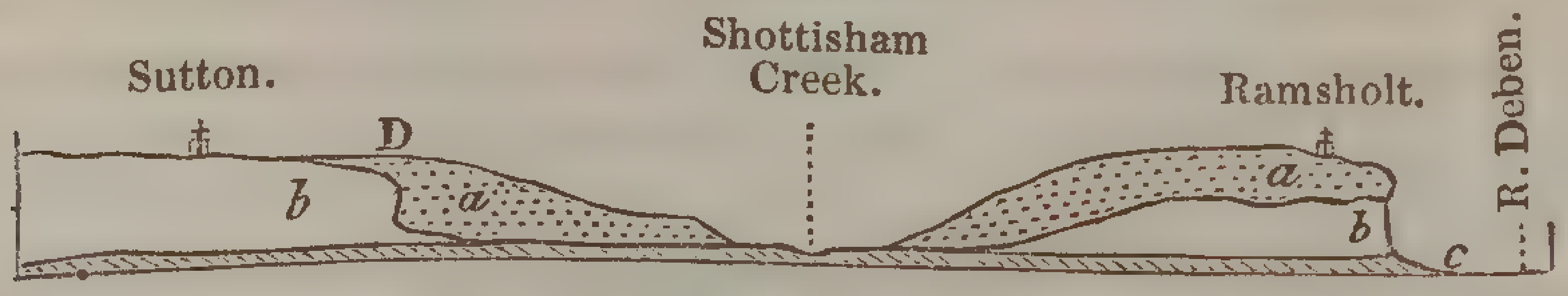
* See paper by E. Charlesworth, Esq.; London and Ed. Phil. Mag. No. xxxviii. p. 81., Aug. 1835.

† Ehrenberg proposed in 1831 the term *Bryozoum*, or "Moss-animal," for the molluscous or ascidian form of polyp, characterized by having two openings to the digestive sack, as in *Eschara*, *Flustra*, *Retepora*, and other zoophytes popularly included in the corals, but now classed by naturalists as mollusca. The term *Polyzoum*, synonymous with *Bryozoum*, was, it seems, proposed in 1830, or the year before, by Mr. J. O. Thompson, but is less generally adopted. The animals of the *Zoantharia* of Milne Edwards and Haime, or the true corals, have only one opening to the stomach.

corals of the deposits in Suffolk, we are indebted to the labours of Mr. Searles Wood. Of testacea alone he has obtained 230 species from the Red, and 345 from the Coralline Crag, about 150 being common to each. The proportion of recent species in the new group is considered by Mr. Wood to be about 70* per cent., and that in the older or Coralline about 60. When I examined these shells of Suffolk in 1835, with the assistance of Dr. Beck, Mr. George Sowerby, Mr. Searles Wood, and other eminent conchologists, I came to the opinion that the extinct species predominated very decidedly in number over the living. Recent investigations, however, have thrown much new light on the conchology of the Arctic, Scandinavian, British, and Mediterranean Seas. Many of the species formerly known only as fossils of the Crag, and supposed to have died out, have been dredged up in a living state from depths not previously explored. Other recent species, before regarded as distinct from the nearest allied Crag fossils, have been observed, when numerous individuals were procured, to be liable to much greater variation, both in size and form, than had been suspected, and thus have been identified. Consequently, the Crag fauna has been found to approach much more nearly to the recent fauna of the Northern, British, and Mediterranean Seas than had been imagined. The analogy of the whole group of testacea to the European type is very marked, whether we refer to the large development of certain genera in number of species or to their size, or to the suppression or feeble representation of others. The indication also afforded by the entire fauna of a climate not much warmer than that now prevailing in corresponding latitudes, prepares us to believe that they are not of higher antiquity than the Older Pliocene era.

The position of the Red Crag in Essex to the subjacent London clay and chalk has been already pointed out (fig. 148.). Whenever the two divisions are met with in the same district, the Red Crag lies uppermost; and, in some cases, as in the section represented in fig. 149., which I had an opportunity of seeing exposed to view in 1839, it is clear that the older or Coralline mass *b* had suffered denudation, before the newer formation *a* was thrown down upon it.

Fig. 149.



Section near Ipswich, in Suffolk.

a. Red Crag. *b*. Coralline Crag. *c*. London Clay.

At D there is not only a distinct cliff, 8 or 10 feet high, of Coralline Crag, running in a direction N.E. and S.W., against which the red crag abuts with its horizontal layers; but this cliff occasionally overhangs. The rock composing it is drilled everywhere by *Pholades*, the holes which they perforated having been afterwards filled

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* See Monograph on the Crag Mollusca. Searles Wood, Paleont. Soc. 1848.

with sand and covered over when the newer beds were thrown down. As the older formation is shown by its fossils to have accumulated in a deeper sea (15, and sometimes 25, fathoms deep or more), there must no doubt have been an upheaval of the sea-bottom before the cliff here alluded to was shaped out. We may also conclude that so great an amount of denudation could scarcely take place, in such incoherent materials, without many of the fossils of the inferior beds becoming mixed up with the overlying crag, so that considerable difficulty must be occasionally experienced by the palæontologists in deciding which species belong severally to each group.

The Red Crag being formed in a shallower sea, often resembles in structure a shifting sand-bank, its layers being inclined diagonally, and the planes of stratification being sometimes directed in the same quarry to the four cardinal points of the compass, as at Butley. That in this and many other localities, such a structure is not deceptive or due to any subsequent concretionary rearrangement of particles, or to mere lines of colour, is proved by each bed being made up of flat pieces of shell which lie parallel to the planes of the smaller strata.

Some fossils, which are very abundant in the Red Crag, have never been found in the white or coralline division; as, for example, the *Fusus contrarius* (fig. 150.), and several species of *Murex* and *Buccinum* (or *Nassa*) (see figs. 151, 152.), which two genera seem wanting in the lower crag.

Fig. 150. Fossils characteristic of the Red Crag.

Fusus contrarius.

Fig. 151.

Murex alveolatus.

Fig. 152.

Nassa granulata.

Fig. 153.

Cypræa coccinelloides.

Fig. 150. half nat. size; the others nat. size.

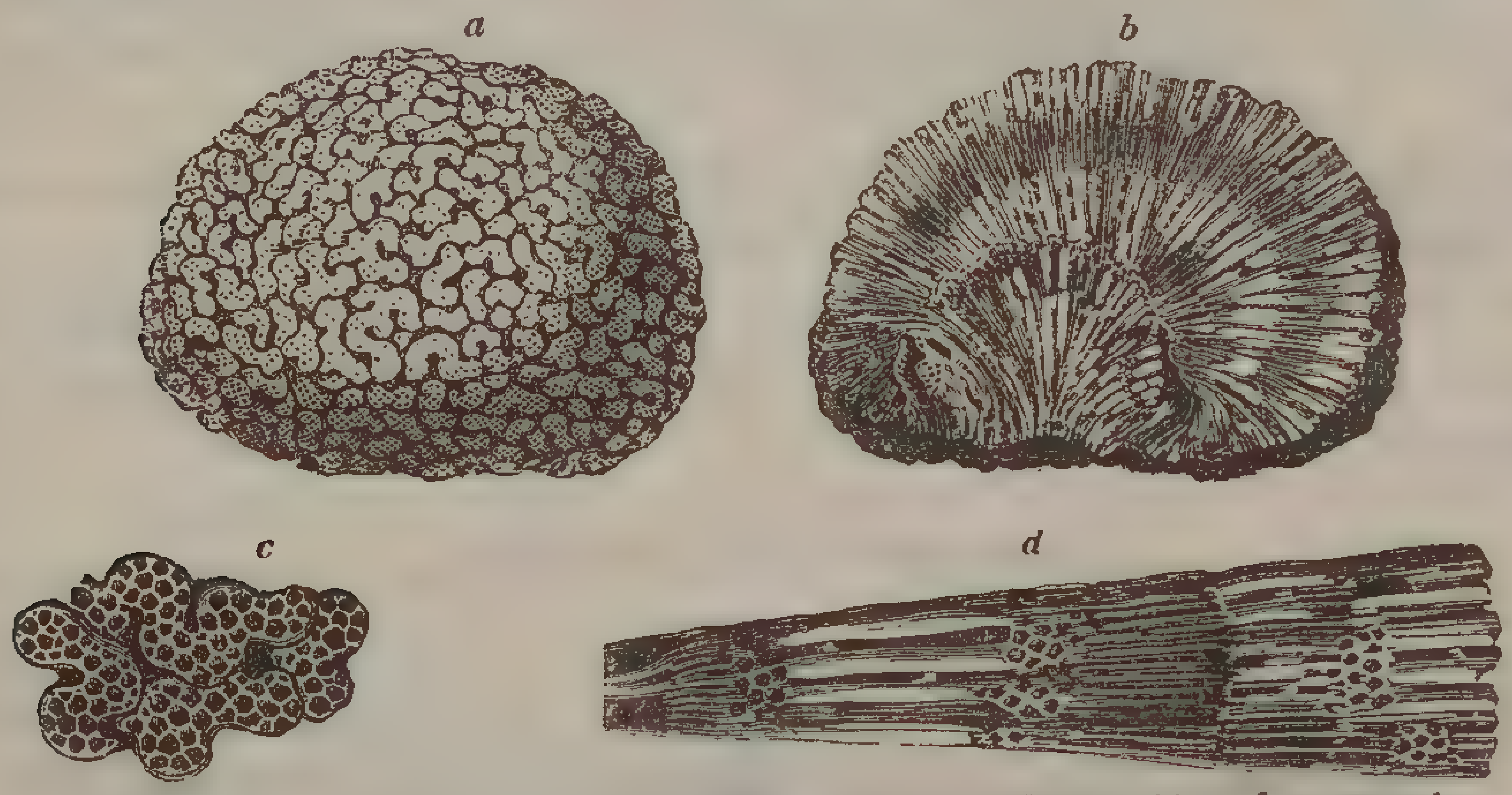
Among the bones and teeth of fishes are those of large sharks (*Carcharodon*), and a gigantic skate of the extinct genus *Myliobates*, and many other forms, some common to our seas, and many foreign to them. It is questionable, however, whether all these can really be ascribed to the era of the Red Crag. Not a few of them may possibly have been derived from older strata, especially from those Upper Eocene formations to be described in the next chapter, which are largely developed in Belgium, and of which a fragment (the Hempstead beds of Forbes) escaped denudation in England.

The distinctness of the fossils of the Coralline from those of the

Red Crag, arises in part from their higher antiquity, and, in some degree, from a difference in the geographical conditions of the submarine bottom. The prolific growth of corals, echini, and a prodigious variety of testacea and bryozoa, implies a region of deeper and more tranquil water; whereas, the Red Crag may have been formed afterwards on the same spot, when the water was shallower. In the mean time the climate may have become somewhat cooler, and some of the zoophytes which flourished in the first period may have disappeared, so that the fauna of the Red Crag acquired a character somewhat more nearly resembling that of our northern seas, as is implied by the large development of certain sections of the genera *Fusus*, *Buccinum*, *Purpura*, and *Trochus*, proper to higher latitudes, and which are wanting or feebly represented in the inferior crag.

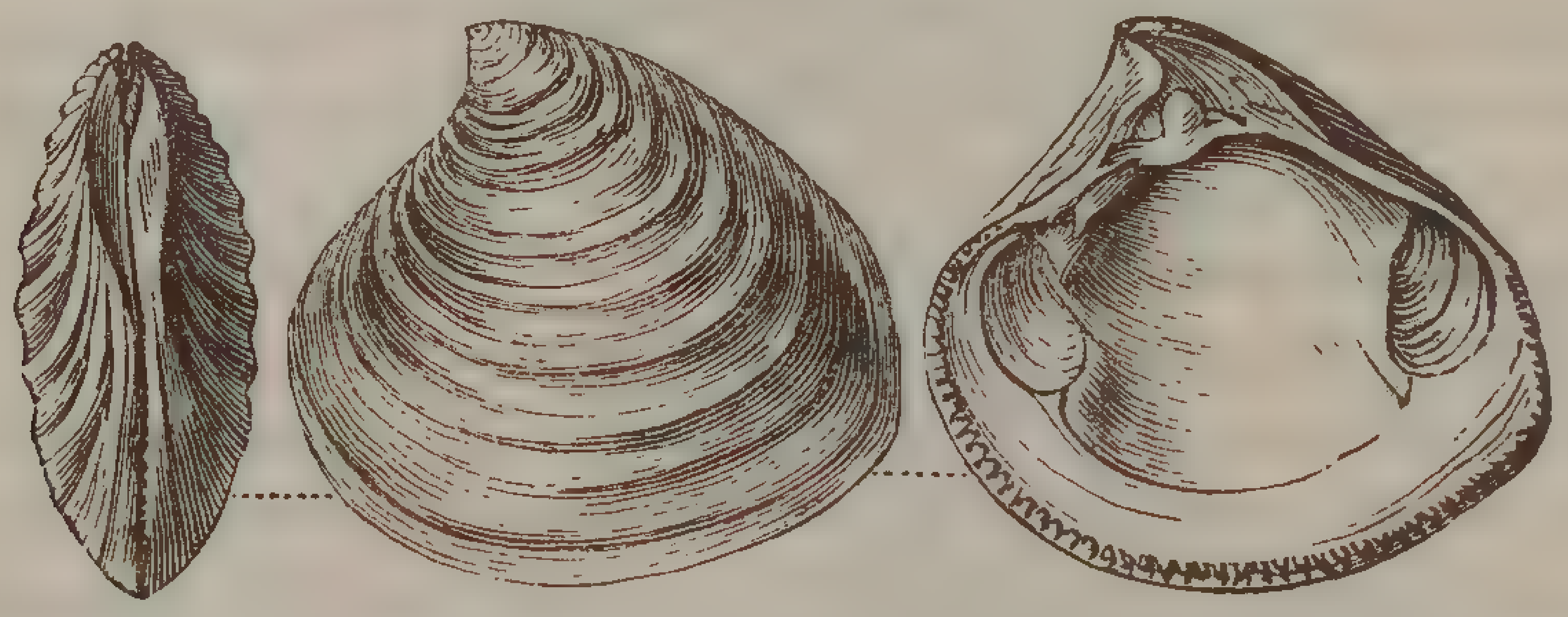
Some of the corals and bryozoa of the lower crag of Suffolk belong to genera unknown in the living creation, and of a very peculiar structure; as, for example, that represented in the annexed fig. (154.), which is one of several species having a globular form. The great number and variety of these zoophytes probably indicate an equable climate, free from intense cold in winter. On the other hand, that the heat was never excessive is confirmed by the prevalence of northern forms among the testacea, such as the *Glycimeris*, *Cyprina*, and *Astarte*. Of the genus last mentioned (see fig. 155.) there are

Fig. 154.



Fascicularia aurantium, Milne Edwards. Family, *Tubuliporidæ*, of same author.
Bryozoan of extinct genus, from the inferior or Coralline Crag, Suffolk.
a. exterior. *b.* vertical section of interior. *c.* portion of exterior magnified.
d. portion of interior magnified, showing that it is made up of long, thin, straight tubes, united in conical bundles.

Fig. 155.



Astarte (*Crassina*, Lam.); species common to upper and lower crag.
Astarte Omalii, Lajonkaire; Syn. *A. bipartita*, Sow. Min. Con. T. 521. f. 3.; a very variable species, most characteristic of the Coralline Crag, Suffolk.

about fourteen species, many of them being rich in individuals; and there is an absence of genera peculiar to hot climates, such as *Conus*, *Oliva*, *Mitra*, *Fasciolaria*, *Crassatella*, and others. The cowries (*Cypræa*, fig. 153.), also, are small, and belong to a section (*Trivia*) now inhabiting the colder regions. A large volute, called *Voluta Lamberti* (fig. 156.), may seem an exception; but it differs in form from the volutes of the torrid zone, and may, like the living *Voluta Magellanica*, have been fitted for an extra-tropical climate.

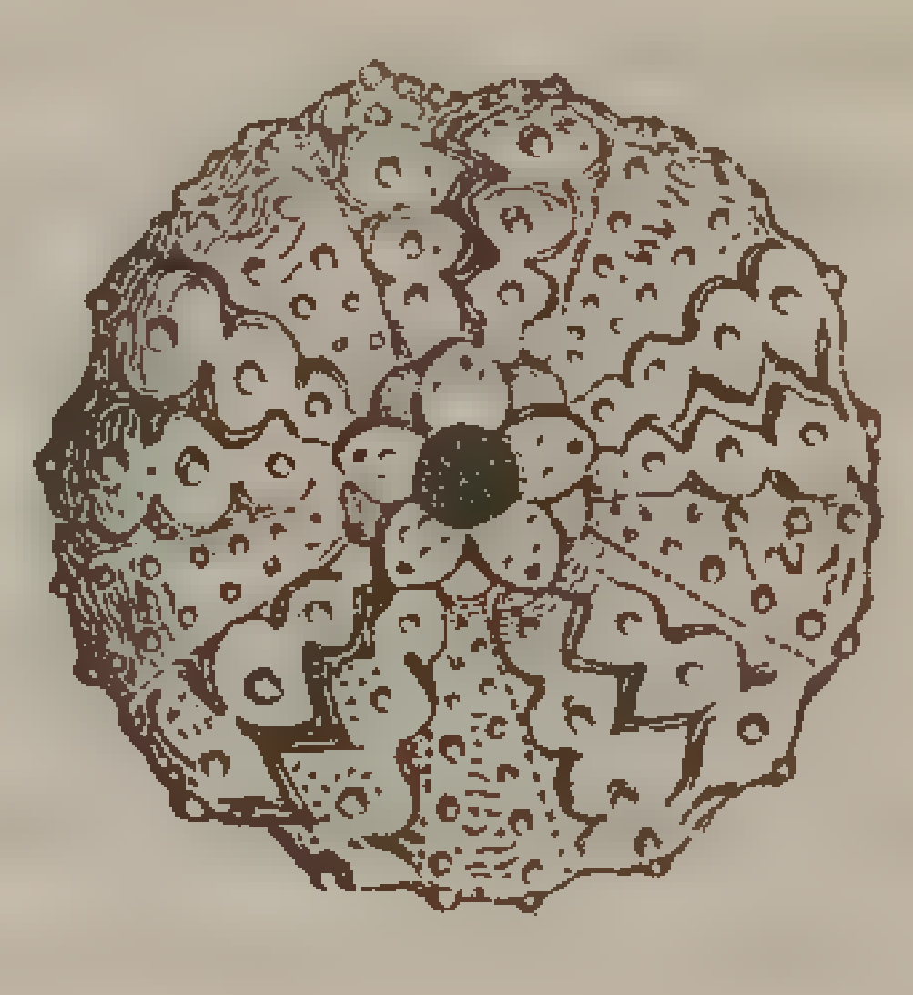
Fig. 156.

Voluta Lamberti, young individ., Cor. and Red Crag.

Fig. 157.

Pyrula reticulata, Lam.; Coralline Crag, Ramsholt.

Fig. 158.



Temnechinus excavatus, Forbes; *Temnopleurus excavatus*, Wood; Cor. Crag, Ramsholt.

The occurrence of a species of *Lingula* at Sutton (see fig. 160.) is worthy of remark, as these *Brachiopoda* seem now confined to more equatorial latitudes; and the same may be said still more decidedly of a species of *Pyrula*, supposed by Mr. Wood to be identical with *P. reticulata* (fig. 157.), now living in the Indian Ocean. A genus also of echinoderms, called by Professor Forbes *Temnechinus* (fig. 158.), is peculiar to the Red and Coralline Crag of Suffolk. The only species now living occur in the Indian Ocean. Whether, therefore, we may incline to the belief that the mean annual temperature was higher or lower than now, we may at least infer that the climate and geographical conditions were by no means the same at the period of the Suffolk Crag as those which now prevail in the same region.

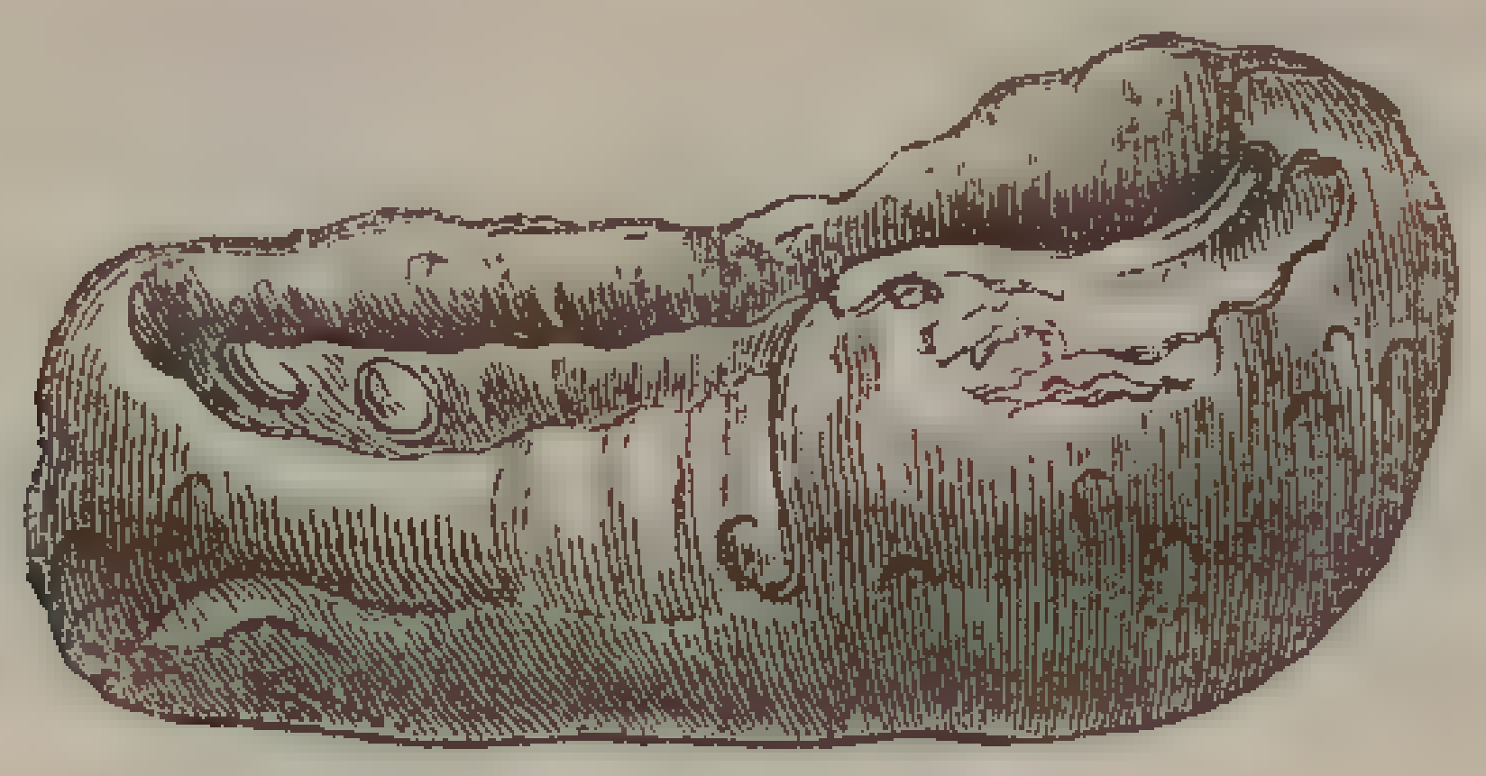
One of the most interesting conclusions deduced from a careful comparison of the shells of these British Older Pliocene strata and the fauna of our present seas, has been pointed out by Prof. E. Forbes. It appears that, during the glacial period, a period intermediate, as we have seen, between that of the crag and our own time, many shells, previously established in the temperate zone, retreated southwards to avoid an uncongenial climate. The Professor has given a list of fifty shells which inhabited the British seas while the Coralline and Red Crag were forming, and which, though now living in our seas, are all wanting in the Pleistocene or glacial deposits. They must therefore, after their migration to the south, which took place during the glacial period, have made their way northwards again. In corroboration of these views, it is stated that all these fifty species occur fossil in the Newer Pliocene strata of

Sicily, Southern Italy, and the Grecian Archipelago, where they may have enjoyed, during the era of floating icebergs, a climate resembling that now prevailing in higher European latitudes.*

In the Red Crag at Felixstow, in Suffolk, Professor Henslow has found the ear-bones of one or more species of cetacea, which, according to Prof. Owen, are the remains of true whales of the family *Balænidæ* (fig. 159.). Mr. Wood is of opinion that these cetacea may be of the age of the Red Crag, or if not that they may be derived from the destruction of beds of Coralline Crag.

Antwerp.—Strata of the same age as the Red and Coralline Crag of Suffolk have been long known in the country round Antwerp and on the banks of the Scheldt, below that city. More than 200 species of testacea have been collected by MM. De Wael, Nyst, and others, of which two-thirds have been identified with Suffolk fossils by Mr. Wood. Among these he recognizes *Lingula Dumortieri* of Nyst (fig. 160.), which I found in abundance at Antwerp in 1851, in what is called by M. de Wael the middle crag. More than half of the shells of this Antwerp deposit agree with living species, and these belong in great part to the fauna of our northern seas, though some Mediterranean species are not wanting. I also met with numerous cetacean bones of the genera *Balænoptera* and *Ziphius* in the same formation. They are not at all rolled, as if washed out of older beds, and I infer that the animals to which they belonged once coexisted in the same sea with the associated mollusca.†

Fig. 159.



Tympanic bone of *Balæna emarginata*, Owen; Red Crag, Felixtow.

Fig. 160.

Lingula Dumortieri, Nyst; Antwerp Crag.

Normandy.—I observed in 1840 a small patch of shells corresponding to those of the Suffolk Crag, near Valognes, in Normandy; and there is a deposit containing similar fossils at St. George Bohon, and several places a few leagues to the S. of Carentan, in Normandy; but they have never been traced farther southwards.

Subapennine strata.—The Apennines, it is well known, are composed chiefly of secondary rocks, forming a chain which branches off from the Ligurian Alps and passes down the middle of the Italian peninsula. At the foot of these mountains, on the side both of the Adriatic and the Mediterranean, are found a series of tertiary strata, which form, for the most part, a line of low hills occupying the space between the older chain and the sea. Brocchi, as we have seen (p. 111.), was the first Italian geologist who described this newer group in detail, giving it the name of the Subapennines; and he

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* E. Forbes, Mem. Geol. Survey, Gt. Brit. vol. i. 386.

† Lyell on Belgian Tertiaries, Quart. Journ. Geol. Soc. 1852, p. 382.

classed all the tertiary strata of Italy, from Piedmont to Calabria, as parts of the same system. Certain mineral characters, he observed, were common to the whole ; for the strata consist generally of light brown or blue marl, covered by yellow calcareous sand and gravel. There are also, he added, some species of fossil shells which are found in these deposits throughout the whole of Italy.

We have now, however, satisfactory evidence that the Subapennine beds of Brocchi, although chiefly composed of Older Pliocene strata, belong nevertheless, in part, both to older and newer members of the tertiary series. The strata, for example, of the Superga, near Turin, are Miocene; those of Asti and Parma Older Pliocene, as is the blue marl of Sienna; while the shells of the incumbent yellow sand of the same territory approach more nearly to the recent fauna of the Mediterranean, and may be Newer Pliocene.

The greyish-brown or blue marl of the Subapennine formation is very aluminous, and usually contains much calcareous matter and scales of mica. Near Parma it attains a thickness of 2000 feet, and is charged throughout with marine shells, some of which lived in deep, others in shallow water, while a few belong to freshwater genera, and must have been washed in by rivers. Among these last I have seen the common *Limnea palustris* in the blue marl, filled with small marine shells. The wood and leaves, which occasionally form beds of lignite in the same deposit, may have been carried into the sea by similar causes. The shells, in general, are soft when first taken from the marl, but they become hard when dried. The superficial enamel is often well preserved, and many shells retain their pearly lustre, part of their external colour, and even the ligament which unites the valves. No shells are more usually perfect than the microscopic foraminifera, which abound near Sienna, where more than a thousand full-grown individuals may be sometimes poured out of the interior of a single univalve of moderate dimensions.

The other member of the Subapennine group, the yellow sand and conglomerate, constitutes, in most places, a border formation near the junction of the tertiary and secondary rocks. In some cases, as near the town of Sienna, we see sand and calcareous gravel resting immediately on the Apennine limestone, without the intervention of any blue marl. Alternations are there seen of beds containing fluviatile shells, with others filled exclusively with marine species; and I observed oysters attached to many limestone pebbles. The site of Sienna appears to have been a point where a river, flowing from the Apennines, entered the sea when the tertiary strata were formed.

The sand passes in some districts into a calcareous sandstone, as at San Vignone. Its general superposition to the marl, even in parts of Italy and Sicily where the date of its origin is very distinct, may be explained if we consider that it may represent the deltas of rivers and torrents, which gained upon the bed of the sea where blue marl had previously been deposited. The latter, being composed of the finer and more transportable mud, would be conveyed to a distance, and first occupy the bottom, over which sand and pebbles would afterwards be spread, in proportion as rivers pushed their deltas farther outwards. In some large tracts of yellow sand it is impossible to detect a single fossil, while in other places they occur in profusion. Occasionally the shells are silicified, as at San Vitale, near Parma, from whence I saw two individuals of recent species, one freshwater and the other marine (*Limnea palustris*, and *Cytherea concentrica*, Lam.), both perfectly converted into flint.

Rome.—The seven hills of Rome are composed partly of marine tertiary strata, those of Monte Mario, for example, of the Older Pliocene period, and partly of superimposed volcanic tuff, on the top of which are usually cappings of a fluviatile and lacustrine deposit. Thus, on Mount Aventine, the Vatican, and the Capitol, we find beds of calcareous tufa with incrusted reeds, and recent terrestrial shells, at the height of about 200 feet above the alluvial plain of the Tiber. The tusk of the mammoth has been procured from this formation, but the shells appear to be all of living species, and must have been imbedded when the summit of the Capitol was a marsh, and constituted one of the lowest hollows of the country as it then existed. It is not without interest that we thus discover the extremely recent date of a geological event which preceded an historical era so remote as the building of Rome.

Aralo-Caspian formations.—This name has been given by Sir R. Murchison and M. de Verneuil to the limestone and associated sandy beds, of brackish-water origin, which have been traced over a very extensive area surrounding the Caspian, Azof, and Aral Seas, and parts of the northern and western coasts of the Black Sea. The fossil shells are partly freshwater, as *Paludina*, *Neritina*, &c., and partly marine, of the family *Cardiaciæ* and *Mytili*. The species are identical, in great part, with those now inhabiting the Caspian; and when not living, they are analogous to forms now found in the inland seas of Asia, rather than to oceanic types. The limestone rises occasionally to the height of several hundred feet above the sea, and is supposed to indicate the former existence of a vast inland sheet of brackish water as large as the Mediterranean, or larger.

The proportion of recent species agreeing with the fauna of the Caspian is so considerable as to leave no doubt in the minds of the geologists above cited, that this rock, also called by them the "Steppe Limestone," belongs to the Pliocene period.*

MIOCENE FORMATIONS.

Faluns of Touraine.—The strata which we meet with next in the descending order are those called by many geologists "Middle Tertiary," and for which in 1833 I proposed the name of Miocene, selecting the faluns of the valley of the Loire in France as my example or type. No strata contemporaneous with these formations have as yet been met with in the British Isles, where the lower crag of Suffolk is the deposit nearest in age. The term "faluns" is given provincially by French agriculturists to shelly sand and marl

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* Geol. of Russia, p. 279. &c.

spread over the land in Touraine, just as the "crag" was formerly much used to fertilize the soil in Suffolk. Isolated masses of such faluns occur from near the mouth of the Loire, in the neighbourhood of Nantes, to as far inland as a district south of Tours. They are also found at Pontlevoy, on the Cher, about 70 miles above the junction of that river with the Loire, and 30 miles S. E. of Tours. Deposits of the same age also appear under new mineral conditions near the towns of Dinan and Rennes, in Brittany. I have visited all the localities above enumerated, and found the beds on the Loire to consist principally of sand and marl, in which are shells and corals, some entire, some rolled, and others in minute fragments. In certain districts, as at Doué, in the department of Maine and Loire, 10 miles S. W. of Saumur, they form a soft building-stone, chiefly composed of an aggregate of broken shells, bryozoa, corals, and echinoderms, united by a calcareous cement; the whole mass being very like the Coralline Crag near Aldborough and Sudbourn in Suffolk. The scattered patches of faluns are of slight thickness, rarely exceeding 50 feet; and between the district called Sologne and the sea they repose on a great variety of older rocks; being seen to rest successively upon gneiss, clayslate, various secondary formations, including the chalk; and, lastly, upon the upper freshwater limestone of the Parisian tertiary series, which, as before mentioned (p. 111.), stretches continuously from the basin of the Seine to that of the Loire.

At some points, as at Louans, south of Tours, the shells are stained of a ferruginous colour, not unlike that of the Red Crag of Suffolk. The species are, for the most part, marine, but a few of them belong to land and fluviatile genera. Among the former, *Helix turonensis* (fig. 45. p. 30.) is the most abundant. Remains of terrestrial quadrupeds are here and there intermixed, belonging to the genera Deinotherium (fig. 161.), Mastodon, Rhinoceros, Hippopotamus, Chæropotamus, Dichobune, Deer, and others, and these are accompanied by cetacea, such as the Lamantine, Morse, Sea-calf, and Dolphin, all of extinct species.

Fig. 161.

Deinotherium giganteum, Kaup.

Professor E. Forbes, after studying the fossil testacea which I obtained from these beds, informs me that he has no doubt they were formed partly on the shore itself at the level of low water, and partly at very moderate depths, not exceeding ten fathoms below that level. The molluscous fauna of the "faluns" is on the whole much more littoral than that of the Red and Coralline Crag of Suffolk, and implies a shallower sea. It is, moreover, contrasted with the Suffolk Crag by the indications it affords of an extra-European climate. Thus it contains seven species of *Cypræa*, some larger than any existing cowry of the Mediterranean, several species of *Oliva*, *Ancillaria*, *Mitra*, *Terebra*, *Pyrula*, *Fasciolaria*, and *Conus*. Of the cones there are no less than eight species, some very large, whereas the only European cone is of diminutive size. The genus *Nerita*, and many others, are also represented by individuals of a type now characteristic of equatorial seas, and wholly unlike any Mediterranean forms. These proofs of a more elevated temperature seem to imply the higher antiquity of the faluns as compared with the Suffolk Crag, and are in perfect accordance with the fact of the smaller proportion of testacea of recent species found in the faluns.

Out of 290 species of shells, collected by myself in 1840 at Pontlevoy, Louans, Bossée, and other villages twenty miles south of Tours; and at Savigné, about fifteen miles north-west of that place; seventy-two only could be identified with recent species, which is in the proportion of twenty-five per cent. A large number of the 290 species are common to all the localities, those peculiar to each not being more numerous than we might expect to find in different bays of the same sea.

The total number of testaceous mollusca from the faluns, in my possession, is 302, of which forty-five only were found by Mr. Wood to be common to the Suffolk Crag. The number of corals, including bryozoa and zoantharia, obtained by me at Doué, and other localities before adverted to, amounts to forty-three, as determined by Mr. Lonsdale, of which seven (one of them a zoantharian) agree specifically with those of the Suffolk Crag. Only one has, as yet, been identified with a living species. But it is difficult, notwithstanding the advances recently made by MM. Dana, Milne Edwards, Haime, and Lonsdale, to institute a satisfactory comparison between recent and fossil zoantharia and bryozoa. Some of the genera occurring fossil in Touraine, as the *Astrea*, *Dendrophyllia*, *Lunulites*, have not been found in European seas north of the Mediterranean; nevertheless the zoantharia of the faluns do not seem to indicate on the whole so warm a climate as would be inferred from the shells.

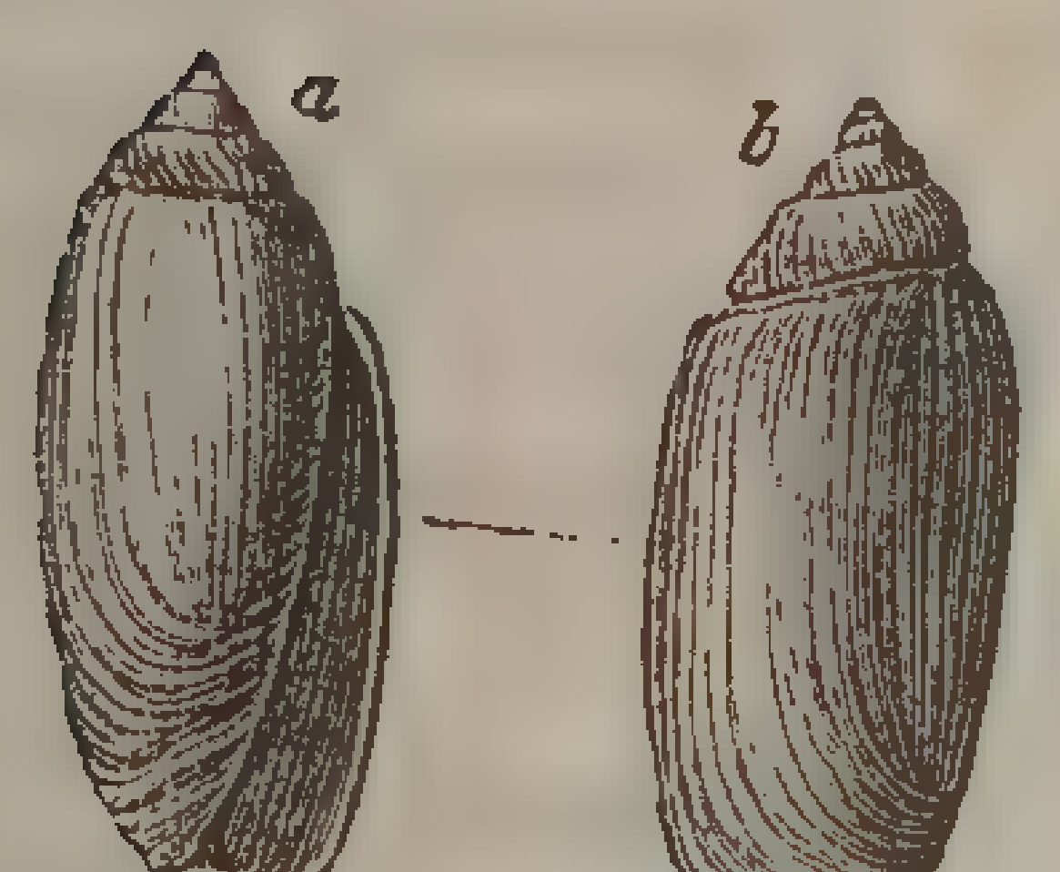
It was stated that, on comparing about 300 species of Touraine shells with about 450 from the Suffolk Crag, forty-five only were found to be common to both, which is in the proportion of only fifteen per cent. The same small amount of agreement is found in the corals also. I formerly endeavoured to reconcile this marked difference in species with the supposed co-existence of the two faunas, by imagining them to have severally belonged to distinct zoological provinces or two seas, the one opening to the north, and the other to the south, with a barrier of land between them, like the Isthmus of Suez, separating the Red Sea and the Mediterranean. But I now abandon that idea for several reasons; among others, because I succeeded in 1841 in tracing the Crag fauna southwards in Normandy to within seventy miles of the Falunian type, near Dinan, yet found that both assemblages of fossils retained their distinctive characters, showing no signs of any blending of species or transition of climate.

On a comparison of 280 Mediterranean shells with 600 British species, made for me by an experienced conchologist in 1841, 160 were found to be common to both collections, which is in the proportion of fifty-seven per cent., a fourfold greater specific resemblance than between the seas of the crag and the faluns, notwithstanding the greater geographical distance between England and the Mediterranean than between Suffolk and the Loire. The principal grounds, however, for referring the English crag to the Older Pliocene and the French faluns to the Miocene epochs, consist in the predominance of fossil shells in the British strata identifiable with species, not only still living, but which are now inhabitants of neighbouring seas, while the accompanying extinct species are of genera such as characterize Europe. In the faluns, on the contrary, the recent species are in a decided minority; and most of them are now inhabitants of the Mediterranean, the coast of Africa, and the Indian Ocean; in a word, less northern in character and pointing to the prevalence of a warmer climate. They indicate a state of things receding farther from the present condition of central Europe in physical geography and climate, and doubtless, therefore, receding farther from our era in time.

Bordeaux.—A great extent of country between the Pyrenees and the Gironde is overspread by tertiary deposits of various ages from the Eocene to the Pliocene. Among these, especially near Saucats in the environs of Bordeaux, and at Mérignac and Bazas in the same region, are sands containing marine shells, and corals of the type of the Touraine faluns.*

Belgium.—In a small hill or ridge called the Bolderberg, which I visited in 1851, situated near Hasselt, about forty miles E. N. E. of Brussels, strata of sand and gravel occur, to which M. Dumont first called attention as appearing to constitute a northern representative of the faluns of Touraine. They are quite distinct in their fossils from the Antwerp Crag before mentioned, and contain shells of the genera *Oliva*, *Conus*, *Ancillaria*, *Pleurotoma*, and *Cancellaria* in abundance. The most common shell is an Olive (see fig. 162.), called by Nyst *Oliva Dufresnii*, Bast.; but which is undoubtedly, as M. Bosquet observes, smaller and shorter than the Bordeaux species.†

Fig. 162.



Fossil *Oliva*, from Bolderberg, Belgium, nat. size. *a*. front view; *b*. back view.

North Germany.—We learn from the able treatise published by M. Beyrich, in 1853, that the fossil fauna above alluded to, which is so meagrely exhibited in the Bolderberg, is rich in species in other localities in North Germany, as in Mecklenburg Lüneburg, the Island Sylt, and at Bersenbrück north of Osnabrück, in Westphalia, where it was first observed by F. Römer. It is also said to occur at Bocholt, and other points in Westphalia; on the borders of Holland; also at Crefeld and Dusseldorf. Not having visited these localities, I can offer no opinion as to the agreement in age of the several deposits here enumerated.

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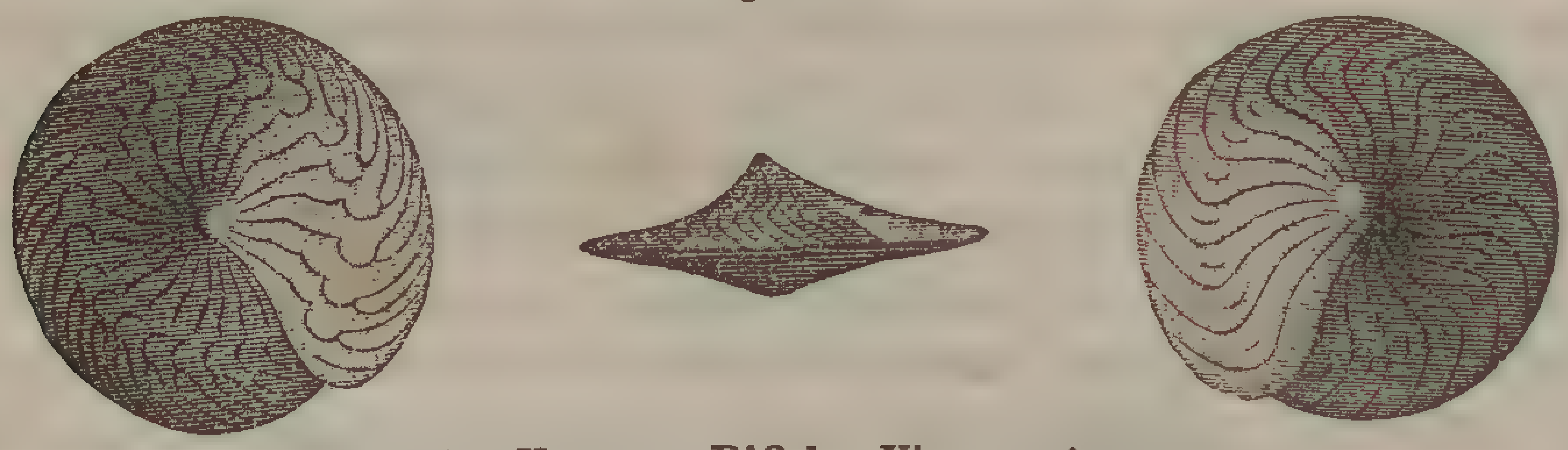
* See a Memoir by V. Raulin, 1848: Bordeaux.

† Lyell on Belgian Tertiaries, Quart. Geol. Journ. 1852, p. 295. Nyst's figure seems to be copied from that given by Basterot of the Bordeaux fossil.

‡ Die Conchylien des Norddeutschen Tertiärgebirge: Berlin, 1853.

Vienna basin.—In South Germany the general resemblance of the shells of the Vienna tertiary basin with those of the faluns of Touraine has long been acknowledged. In Dr. Hörnes' excellent work, recently commenced, on the fossil mollusca of that formation, we see figures of many shells of the genus *Conus*, some of large size, clearly of the same species as those found in the falunian sands of Touraine. M. Alcide d'Orbigny has also shown that the foraminifera of the Vienna basin differ alike from the Eocene and Pliocene species, and agree with those of the faluns, so far as the latter are known. Among the Vienna foraminifera, the genus *Amphistegina* (fig. 163.) is very characteristic, and is supposed by Archiac to take the same place among the foraminifera of the Miocene era, which the Nummulites occupy in the Eocene period.

Fig. 163.



Amphistegina Hauerina, D'Orb. Vienna, miocene strata.

The Vienna basin is thought by some geologists to comprise tertiary strata of more than one age, the lowest strata reached in boring Artesian wells being older than the faluns.

Piedmont. — *Switzerland.* — To the same Miocene or "falunian" epoch, we may refer a portion of the strata of the Hill of the Superga near Turin in Piedmont *, as also part of the Molasse of Switzerland, or the greenish sand which fills the great Swiss valley between the Alps and the Jura. At the foot of the Alps it usually takes the form of a conglomerate called provincially "nagelflue," sometimes attaining the truly wonderful thickness of 6000 and 8000 feet, as in the Rigi near Lucerne and in the Speer near Wesen. The lower portion of this molasse is of freshwater origin.

Scotland. — *Isle of Mull.* — In the sea-cliffs forming the headland of Ardtun on the west coast of Mull, in the Hebrides, several bands of tertiary strata containing leaves of dicotyledonous plants were discovered in 1851 by the Duke of Argyle. † From his description it appears that there are three leaf-beds, varying in thickness from 1½ to 2½ feet, which are interstratified with volcanic tuff and trap, the whole mass being about 130 feet in thickness. A sheet of basalt 40 feet thick covers the whole; and another columnar bed of the same rock 10 feet thick is exposed at the bottom of the cliff. One of the leaf-beds consists of a compressed mass of leaves unaccompanied by any stems, as if they had been blown into a marsh where a species of *Equisetum* grew, of which the remains are plentifully imbedded in clay.

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* See Sig. Giov. Micnelotti's works.

† Quart. Geol. Journ. 1851, p. 89.

It is supposed by the Duke of Argyle that this formation was accumulated in a shallow lake or marsh in the neighbourhood of a volcano, which emitted showers of ashes and streams of lava. The tufaceous envelope of the fossils may have fallen into the lake from the air as volcanic dust, or have been washed down into it as mud from the adjoining land. The deposit is decidedly newer than the chalk, for chalk flints containing cretaceous fossils were detected by the Duke in the principal mass of volcanic ashes or tuff.*

The leaves belong to species, and sometimes even to families, no longer indigenous in the British Isles; and "their climatal aspect," says Prof. E. Forbes, "is more mid-European than that of the English Eocene Flora. They also resemble some of the Miocene plants of Croatia described by Unger." Some of them appear to belong to a coniferous tree, possibly a yew (*Taxus*); others, still more abundant, to a plane (*Platanus*), having the same outline and veining well preserved. No accompanying fossil shells have been met with, and there seems therefore the same uncertainty in determining whether these beds are Upper Eocene or Miocene, which we experience when we endeavour to fix the age of many continental Brown-Coal formations, those of Croatia not excepted.

These interesting discoveries in Mull naturally raise the question, whether the basalt of Antrim in Ireland, and of the celebrated Giant's Causeway, may not be of the same age. For in Antrim the basalt overlies the chalk, and the upper mass of it covers everywhere a bed of lignite and charcoal, in which wood, with the fibre well preserved, and evidently dicotyledonous, is preserved.† The general dearth of strata in the British Isles, intermediate in age between the formation of the Eocene and Pliocene periods, may arise, says Prof. Forbes, from the extent of dry land which prevailed in the vast interval of time alluded to. If land predominated, the only monuments we are likely ever to find of Miocene date are those of lacustrine and volcanic origin, such as these Ardtun beds in Mull, or the lignites and associated basalts in Antrim. On the flaules of Mont Dor, in Auvergne, I have seen leaf beds among the ancient volcanic tuffs which I have always supposed to be of Miocene date. Some of the Brown Coal deposits of Germany are believed to be Miocene; others, as will be seen in the next chapter, are Eocene, Upper or Middle.

Older Pliocene and Miocene formations in the United States.— Between the Alleghany mountains, formed of older rocks, and the Atlantic, there intervenes, in the United States, a low region occupied principally by beds of marl, clay, and sand, consisting of the cretaceous and tertiary formations, and chiefly of the latter. The general elevation of this plain bordering the Atlantic does not exceed 100 feet, although it is sometimes several hundred feet high. Its width in the middle and southern states is very commonly from 100 to 150 miles. It consists, in the South, as in Georgia, Alabama, and South Carolina,

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* Quart. Geol. Journ. 1851, p. 90.

† Duke of Argyll, ibid. p. 101.

almost exclusively of Eocene deposits ; but in North Carolina, Maryland, Virginia, Delaware, more modern strata predominate, which, after examining them in 1842, I supposed to be of the age of the English crag and Faluns of Touraine.* If, chronologically speaking, they can be truly said to be the representatives of these two European formations, they may range in age from the Older Pliocene to the Miocene epoch, according to the classification of European strata adopted in this chapter.

The proportion of fossil shells agreeing with recent, out of 147 species collected by me, amounted to about 17 per cent, or one-sixth of the whole; but as the fossils so assimilated were almost always the same as species now living in the neighbouring Atlantic, the number may hereafter be augmented, when the recent fauna of that ocean is better known. In different localities, also, the proportion of recent species varied considerably.

On the banks of the James River, in Virginia, about 20 miles below Richmond, in a cliff about 30 feet high, I observed yellow and white sands overlying an Eocene marl, just as the yellow sands of the crag lie on the blue London clay in Suffolk and Essex in England. In the Virginian sands, we find a profusion of an Astarte (*A. undulata*, Conrad), which resembles closely, and may possibly be a variety of, one of the commonest fossils of the Suffolk Crag (*A. bipartita*); the other shells also, of the genera *Natica, Fissurella, Artemis, Lucina, Chama, Pectunculus*, and *Pecten*, are analogous to shells both of the English crag and French faluns, although the species are almost all distinct. Out of 147 of these American fossils I could only find 13 species common to Europe, and these occur partly in the Suffolk Crag, and partly in the faluns of Touraine; but it is an important characteristic of the American group, that it not only contains many peculiar extinct forms, such as *Fusus quadricostatus*, Say (see fig. 165.) and *Venus tridacnoides*, abundant in these same formations, but also some shells which, like *Fulgur carica* of Say and *F. canaliculatus* (see fig. 164.), *Calyptræa costata, Venus mercenaria*,

Fig. 164.

Fulgur canaliculatus. Maryland.

Fig. 165.

Fusus quadricostatus, Say. Maryland.

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* Proceed. of the Geol. Soc. vol. iv. part 3. 1845, p. 547.

Lam., *Modiola glandula*, Totten, and *Pecten magellanicus*, Lam., are recent species, yet of forms now confined to the western side of the Atlantic, — a fact implying that some traces of the beginning of the present geographical distribution of mollusca date back to a period as remote as that of the Miocene strata.

Of ten species of zoophytes which I procured on the banks of the James River, one was formerly supposed by Mr. Lonsdale to be identical with a fossil from the faluns of Touraine, but this species (see fig. 166.) proves on re-examination to be different, and to agree generically with a coral now living on the coast of the United States. With respect to climate, Mr. Lonsdale regards these corals as indicating a temperature exceeding that of the Mediterranean, and the shells would lead to similar conclusions. Those occurring on the James River are in the 37th degree of N. latitude, while the French faluns are in the 47th; yet the forms of the American fossils would scarcely imply so warm a climate as must have prevailed in France when the Miocene strata of Touraine originated.

Fig. 166.

Astrangia lineata, Lonsdale.
Syn. *Anthophyllum lineatum.*
Williamsburg, Virginia.

Among the remains of fish in these Post-Eocene strata of the United States are several large teeth of the shark family, not distinguishable specifically from fossils of the faluns of Touraine.

India. — *Sewâlik Hills.* — The freshwater deposits of the sub-Himalayan or Sewâlik Hills, described by Dr. Falconer and Captain Cautley, belong probably to some part of the Miocene period, although it is difficult to decide this question until the accompanying freshwater and land shells have been more carefully determined and compared with fossils of other tertiary deposits. The strata are certainly newer than the nummulitic rocks of India, and, like the faluns of Touraine, they contain the genera *Deinotherium* and *Mastodon*, with which are associated no less than seven extinct species of Elephants. The presence of a fossil giraffe and hippopotamus, genera now only living in Africa, and of a camel, an inhabitant of extensive plains, implies a former geographical state of things strongly contrasted with what now prevails in the same region. A species of *Anoplotherium* (*A. posterogenitum*) forms a link between this fauna and that of the Eocene period; yet, on the whole, the Sewâlik mammalia have a more modern aspect than those of the Upper Eocene, so many being referable to existing genera, whereas almost every Eocene genus is extinct. Moreover, the sub-Himalayan fauna exhibits a great development of the Ruminants, an order so feebly represented in the Eocene period. In addition to the camel and giraffe already alluded to, we have here the huge Sivatherium, a ruminant bigger than the rhinoceros, and provided with a large upper lip, if not a short proboscis, and having two pair of horns resembling those of antelopes. The number of species of the genus Antelope is also remarkable. In the same fauna appear many carnivorous beasts, often belonging to existing genera, and several species of monkey. Among the reptiles are crocodiles, some larger than any now living; and an enormous tortoise, *Testudo Atlas,* the curved shell of which measured twenty feet across.

CHAPTER XV.

UPPER EOCENE FORMATIONS.

(*Lower Miocene of many authors.*)

Preliminary remarks on classification, and on the line of separation between Eocene and Miocene strata — Whether the Limburg and contemporaneous formations should be called Upper Eocene — Limburg strata in Belgium — Strata of same age in North Germany — Mayence basin — Brown Coal of Germany — Upper Eocene of Hempstead Hill, Isle of Wight — Upper Eocene of France — Lacustrine strata of Auvergne — Indusial limestone — Freshwater strata of the Cantal — Its resemblance in some places to white chalk with flints — Proofs of gradual deposition — Upper Eocene of Bordeaux, Aix-en-Provence, Malta, &c. — Upper Eocene of Nebraska, United States.

Preliminary remarks. — In the last chapter it was stated that as yet we know of no marine strata in the British Isles contemporaneous with the faluns of Touraine, or those shelly deposits of the valley of the Loire which I selected as the type of the Miocene period. There have, however, been recently discovered in the Isle of Wight certain fluvio-marine deposits, which many continental geologists would call " Lower Miocene," the " faluns " being termed by them " Upper Miocene." A few preliminary remarks on this difference of nomenclature, bearing as it does on questions involving the first principles of classification, will be necessary before I treat of the Upper Eocene formations.

The marine strata, which in the north of France come next in chronological order to the "faluns," or which immediately precede them in age, are the sands and sandstones, called the " Grès de Fontainebleau," or " sables marins supérieurs." (See General Table, p. 105.) They constitute the uppermost beds of the Paris basin, and are overlaid by a freshwater limestone called " Calcaire de la Beauce." The upper marine sands contain no fossil shells common to the faluns, or extremely few species, ; and no shells of living species, or, if so, they are about as scarce as in the Middle or typical Eocene groups. In consequence of this distinctness in the fossils, and for other reasons, presently to be mentioned, I excluded these " upper sands" from the Miocene period in former editions of this work, availing myself of the hiatus between the Grès de Fontainebleau and the faluns to draw a line of separation between Eocene and Miocene. In support of this classification I pointed out the fact that the " upper marine sands," or

Grès de Fontainebleau of the Parisian series, with their characteristic shells, extend southwards from the French metropolis, as far as Etampes, which is within seventy miles of Pontlevoy, near Blois, and not more than 100 miles from Savigné, near Tours, two localities where the *falunian* shells are very abundant. So remarkable a difference between the species of the valley of the Loire and those of the valley of the Seine cannot be the result of geographical distribution at one and the same former era, but must evidently have depended on a difference in the age of the deposits. It marks the influence of Time, and not of Space.

Another reason which induced me to class the Grès de Fontainebleau and strata of the same age with the older series rather than with the newer, was the decidedly Eocene aspect of the testaceous fauna, and the fact that a certain proportion of the shells of the "upper sands" are of species common to the underlying Parisian strata.

A different arrangement, however, was adopted by MM. Dufrénoy and E. de Beaumont, in their colouring of the Government Map of France, for they comprehended in their Miocene group, not only the faluns of Touraine, but also the freshwater "calcaire de la Beauce," and the marine sands and sandstone (Grès de Fontainebleau), *i. e.* all the tertiary deposits which lie above the gypseous series of Montmartre, a formation well known as rich in extinct mammalia, first brought to light by the genius of Cuvier. M. D'Archiac, in 1839, followed the same mode of classification, dividing what he termed "Lower" from his "Middle tertiary" in the same way. M. Deshayes, in his work on the Fossil Shells of the Environs of Paris (1824—1837), had given twenty-nine species as belonging to the upper marine strata, nearly all of which he distinguished specifically from shells of the *Calcaire Grossier*, although he regarded them as characteristic of the same fauna. The railway cuttings near Etampes, in 1849, enabled M. Hébert to raise the number to ninety, and he first pointed out that most of them agreed specifically with shells of Kleyn Spawen, near Maestricht, in Belgium, and with those of Rupelmonde and other places near Antwerp. These Belgian fossils had been described by MM. Nyst, De Koninck, and Bosquet, and their geological position had been accurately ascertained by M. Dumont, and placed by him above the Brussels tertiary beds, which are the undoubted representatives of the *Calcaire Grossier* of Paris, a typical Eocene group. M. de Koninck, about the same time, remarked that the Kleyn Spawen, or "Limburg" fossils, were in part identical with those of the Mayence tertiary basin, a group which in my first editions I had assigned to the Miocene period. M. Beyrich more recently (1850) has described a formation of the same age as that of Kleyn Spawen, occurring within seven miles of the gates of Berlin, near the village of Hermsdorf; and has shown that about a third of the species agreed with known Belgian shells of the age of the Grès de Fontainebleau, while about a fifth are English and French Middle Eocene species.

In 1851, I examined with care the Belgian formations at Rupelmonde and Boom, near Antwerp, and in the Limburg, near Maestricht, and was able, with the assistance of M. Bosquet, to give a table of no less than 201 species of shells of the era under consideration. Of these more than a third proved to be identical with English Eocene testacea, even when I restricted the term Eocene to its most limited sense, extending it no farther upwards than the Middle Eocene or nummulitic formations.* For this reason I called the Limburg or Kleyn Spawen beds Upper Eocene, giving as my reason "that they resembled the older formations in their fossils as much as some of the different divisions of the Eocene series in France and England resemble each other; as much, for example, as the Barton Clay in Hampshire agrees with the London Clay proper, or the Calcaire Grossier with the Soissonnais sands in France."

Subsequently, in the winter of 1852, Professor Edward Forbes examined near Yarmouth, in the Isle of Wight, a deposit occupying a very limited area, but about 170 feet in thickness, which he first determined to be of the same age as the Limburg beds. They were found to be in comformable position with the other tertiary strata previously known in that island, and to contain abundantly some of the most characteristic Kleyn Spawen fossils. He named this deposit "the Hempstead series," and classed it as Upper Eocene, for reasons similar to those which had induced me so to name the Limburg beds of Belgium. They cannot in fact be separated from the subjacent Eocene strata without drawing a line of demarcation confessedly arbitrary, and which would leave a great many of the same species of fossils above and below it. So complete, indeed, is the passage from the Bembridge series (an equivalent of the gypsum of Montmartre, and, therefore, an acknowledged Eocene formation) into the Hempstead beds, that Professor Forbes places both groups together in his Upper Eocene division, drawing the line between Upper and Middle Eocene at the base of the Bembridge beds.

In opposition to this view two recent authorities, who in the course of the present year (1853) have written on the tertiary formations of Germany, M. Beyrich, before cited †, and Dr. Sandberger ‡, contend that all strata, parallel in age with the Limburg, should be termed Lower Miocene. M. Beyrich affirms that if the strata of the Bolderberg in Belgium, and numerous deposits of contemporaneous date of Northern Germany already enumerated (p. 179.), be of the age of the "faluns," then it can be shown that these same beds have so many fossils in common with the Limburg strata, that the latter may fairly be regarded as Miocene, or as an older deposit of the same great period; and he goes on to say that, unless we are prepared to allow the Eocene division to absorb all the overlying tertiary formations, we must begin a new series from the base of the Limburg upwards, calling the latter Lower Miocene.

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* Quart. Geol. Journ. 1852, vol. viii. p. 322.

† Die Conchylien des Norddeutsch. Tertiärgeb.: Berlin, 1853.

‡ Uber das Mainzer Tertiärbeckens, &c.: Wiesbaden, 1853.

Dr. Sandberger divides the strata of the Mayence basin into two sections, an older and a newer, the former confessedly the equivalent of the Limburg (or Hempstead) beds, while in the upper he finds some fossil remains, which appear to him to have a more modern character. But when we separate from this higher division the sands of Eppelsheim, containing bones of *Deinotherium* and *Mastodon longirostris*, which are most probably of falunian age, the rest of his upper series may be as old as the Limburg beds, though, for want of good sections, there is much obscurity in regard to the grouping of the beds. Dr. Sandberger, however, gives a list of twelve shells, besides some teeth of fish and other fossils, which are common to the Mayence basin and the Hesse-Cassel sands. Now the latter were classed as Subapennine or Pliocene by Philippi, and, although we have as yet no sufficient data for determining their true age, appear clearly to belong to a more modern fauna than that of the Mayence basin. If such a relationship could be established between the two as to indicate a passage from the Hesse-Cassel fauna to that of the Mayence beds, this fact would doubtless go some way towards bearing out the views of the author.

The reader has probably by this time begun to perceive that one cause of embarrassment, experienced in the classification of these tertiary formations, arises from the discovery of several missing links in the chain of historical records. I may remind him that for more than twenty years I have advocated in the Principles of Geology the doctrine that there has been a continual coming in of new species, and dying out of old ones, and a gradual change in the physical geography and climate of the earth, and not such a reiteration of sudden revolutions in the animate and inanimate worlds, as was once insisted upon by many English geologists of note, and is still maintained by not a few of the most distinguished continental writers. When, therefore, I proposed in 1833 the term Miocene for the faluns of Touraine, the fossil shells of which, according to the determination of M. Deshayes, contained an admixture of about seventeen in the hundred of recent species, I foretold that from time to time new sets of strata would come to light, and require to be intercalated between those already described, and in that case that the fossils of newly-found beds would "deviate from the normal types first selected, and approximate more and more to the types of the antecedent or subsequent epochs." According to this view, it was obvious from the first that the oldest Miocene records, whenever they were detected, would not be easily distinguishable from the youngest members of the Eocene series, especially in the proportion of the living to the extinct species of fossil shells. The importance, indeed, of the latter test must diminish rapidly the more we recede from the Pliocene and approach the Miocene, and still more the Eocene formations, although it is never without its value, and often furnishes the only common standard of comparison between strata of very distant countries.

I make these allusions to show that I am by no means unprepared for the discovery of gradations from Miocene to Eocene, and for the probable necessity of including hereafter in the Miocene series some fossiliferous groups which may diverge in their characters from the standard first set up, or from the type of the faluns of Touraine. But I have seen, as yet, no sufficient evidence that such a passage, as is here spoken of, has been made out. The limits of the Eocene series have been extended, without as yet filling up the gap between that series and the faluns of Touraine. I am desirous at the same time to explain, that the important point now at issue is not simply one of nomenclature. The difficulty is the same, whether we use the terms Lower and Middle Tertiary, or Eocene and Miocene. To one or other of the periods so named we must refer the Limburg and Hempstead beds, and the sands of the Forest of Fontainebleau. Can we, without doing violence to paleontological principles, refer all these to the same period as the faluns of Touraine? If so, it would be immaterial whether we called them Middle Tertiary, Miocene or "Falunian," or by any other general name. The question is, whether, in the present state of our information, the mass of characteristic fossils of the groups alluded to resemble more nearly the Eocene or the Falunian. I adhere at present to the nomenclature formerly adopted by me for strata described in this chapter, calling them Upper Eocene —not because of the small number of living species of shells found in them, although this is certainly one point of agreement between them and the "nummulitic" Eocene beds, but because of the aspect of the whole fauna, which seems to me to be Eocene rather than Falunian. Among other illustrations of this affinity, I may refer the reader to the numerous and excellent figures of species of the genus *Voluta* given by M. Beyrich from the Limburg beds of North Germany—forms strikingly characteristic of the Barton clay in Hampshire, a regular member of the Middle Eocene group. The faluns are devoid of such forms. Until, therefore, the time arrives when the break between the Limburg beds and the faluns has disappeared more completely, it appears to me safer to include the Limburg and all contemporaneous formations in the Eocene.

At the same time I have drawn the line between Middle and Upper Eocene, as in former editions, excluding from the latter the Bembridge beds of the Isle of Wight, or the gypseous series of Montmartre. A preference is given to this last method, simply for convenience sake, in order that the Upper Eocene of this work may coincide exactly with the strata classed by so many distinguished geologists as Lower Miocene. I am bound, however, to state, that the parting line between the Bembridge and Hempstead series, in the Isle of Wight, has been shown by Prof. Forbes to be an arbitrary one —a purely conventional line, if anything, less marked than the line separating the Bembridge series from the underlying St. Helen's group. (See Table, p. 209.) If retained as more useful, it is, as before hinted, for the sake of conformity with a system of classification adopted by many able geologists, who selected it before the uninterrupted continuity of the Eocene series from its nummulitic or central portions to its Upper or Limburg beds was clearly made out.

LIMBURG STRATA IN BELGIUM.

(*Rupelian and Tongrian Systems of Dumont.*)

The best type which we as yet possess of the Upper Eocene, as defined in the foregoing observations, consists of the beds formerly known to collectors as those of Kleyn Spawen. These can be best studied in the environs of the village so named, which is situated about seven miles west of Maestricht, and in the old province of Limburg in Belgium. In that region, about 200 species of testacea, marine and freshwater, have been obtained, with many foraminifera and remains of fish.

The following table will show the position of the Limburg beds.

MIOCENE.

A. Bolderberg beds, see p. 179., seen near Hasselt.

UPPER EOCENE.

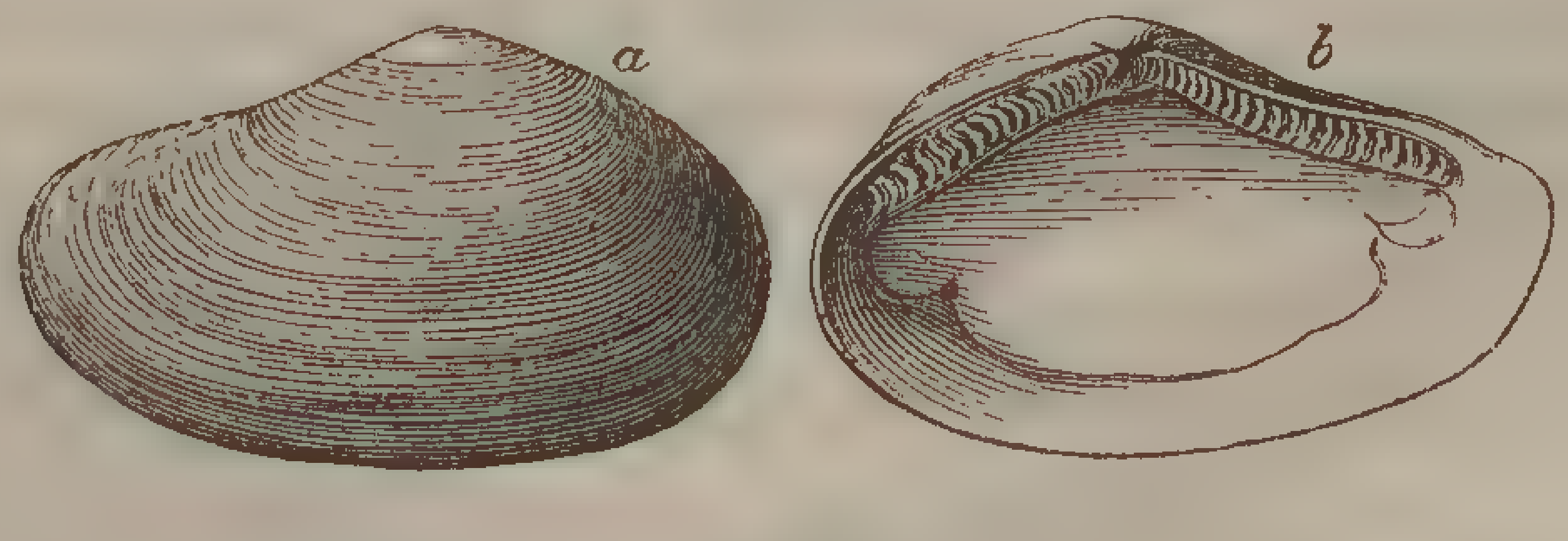
B. 1. Nucula Loam of Kleyn Spawen, same age as clay of Rupelmonde and Boom.	Upper Limburg beds. — Rupelian of Dumont.
B. 2. Fluvio-marine beds of Bergh, Lethen, and other places near Kleyn Spawen.	Middle Limburg beds.—Upper Tongrian of Dumont.
B. 3. Green sand of Bergh, Neerepen, &c., near Kleyn Spawen: Marine.	Lower Limburg beds.—Lower Tongrian of Dumont.

MIDDLE EOCENE.

C. Lacken and Brussels beds, with nummulites, &c.: Louvain and Brussels.

The uppermost of the three subdivisions (B. 1.) into which the Limburg series is separated in the above table, contains at Kleyn Spawen many of the same fossils as the clay of Rupelmonde and Boom, ten miles south of Antwerp, and sixty miles N. W. of Kleyn Spawen. About forty species of shells have been collected from the tile-clay worked on the banks of the Scheldt at the villages above mentioned. At Rupelmonde, this clay attains a thickness of about 100 feet, and much resembles in mineral character the "London Clay," containing like it septaria or concretions of argillaceous limestone traversed by cracks in the interior. The shells have been described by MM. Nyst and De Koninck. Among them *Leda* (or *Nucula*) *Deshayesiana* (see fig. 167.) is by far the most abundant; a fossil unknown as yet in

Fig. 167.



Leda Deshayesiana. Nyst. Syn *Nucula Deshayesiana.*

the English tertiary strata, but when young much resembling *Leda amygdaloides* of the London clay proper (see fig. 227. p. 219.). Among other characteristic shells are *Pecten Hoeninghausii*, and a species of *Cassidaria*, and several of the genus *Pleurotoma*. Not a few of these testacea agree with English Eocene species, such as *Actæon simulatus*, Sow., *Cancellaria evulsa*, Brander, *Corbula pisum* (fig. 170. p. 194.), and *Nautilus ziczac*. They are accompanied by many teeth of sharks, as *Lamna contortidens*, Ag., *Oxyrhina xiphodon*, Ag., *Carcharodon heterodon* (see fig. 211.), Ag., and other fish, some of them common to the Middle Eocene strata. The same deposit, B. 1., is very imperfectly seen at Kleyn Spawen, where the lower divisions B. 2. and B. 3. are much better developed. B. 2. consists of several alternations of sands and marls, in which a greater or less intermixture of fluviatile and marine shells occurs, implying the occasional entrance of a river near the spot, and possibly oscillations in the level of the bottom of the sea. Among the shells are found *Cyrena semistriata* (fig. 171. p. 194.), *Cerithium plicatum*, Lam. (fig. 172. p. 194.), *Rissoa Chastelii*, Bosq. (fig. 174.), and *Corbula pisum* (fig. 170.), four shells all common to the Hempstead beds in the Isle of Wight, to be mentioned in the sequel. With the above, *Lucina Thierensii*, and other marine forms of the genera *Venus*, *Limopsis*, *Trochus*, &c., are met with.

In B. 3., or the Lower Limburg, more than 100 marine shells have been collected, among which the *Ostrea ventilabrum* is very conspicuous. Species common to the underlying Brussels sands, or the Middle Eocene, are numerous, constituting a third of the whole; but most of these are feebly represented in comparison with the more peculiar and characteristic shells, such as *Ostrea ventilabrum*, *Mytilus Nystii*, *Voluta suturalis*, &c.

In none of the Belgian Upper Eocene strata could I find any nummulites; and M. D'Archiac had previously observed that these foraminifera characterize his "Lower Tertiary Series," as contrasted with the Middle, and would therefore serve as a good test of age between Eocene and Miocene, if the line of demarcation be drawn according to his method, or equally so between Upper and Middle Eocene, according to the plan adopted in this work. The same naturalist informs us that one nummulite only has ever yet been seen to penetrate upwards into the middle tertiary, viz. *Nummulites intermedia*, an Eocene species. It has been found in the hill of the Superga near Turin*, in beds usually classed as Miocene, but probably somewhat older than the falunian type.

Hermsdorf, near Berlin.—Professor Beyrich has described a mass of clay, used for making tiles within seven miles of the gates of Berlin, near the village of Hermsdorf, rising up from beneath the sands with which that country is chiefly overspread. This clay is more than forty feet thick, of a dark bluish-grey colour, and, like that of Rupelmonde, contains septaria. Among other shells, the *Leda Deshayesiana* before mentioned (fig. 167.) abounds, together with

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* Archiac, Monogr. pp. 79. 100.

many species of *Pleurotoma*, *Voluta*, &c., a certain proportion of the fossils being identical in species with Limburg and Mayence shells. M. Beyrich enumerates several other localities in North Germany, and particularly one at Magdeburg, and several on the Lower Elbe, where beds of the same age appear.

Mayence basin. — I have already alluded to the elaborate description published by Dr. F. Sandberger of the Mayence tertiary area, which occupies a tract from five to twelve miles in breadth, extending for a great distance along the left bank of the Rhine from Mayence to the neighbourhood of Manheim, and which is also found to the east, north, and south-west of Frankfort. M. De Koninck, of Liége, first pointed out to me that the purely marine portion of the deposit (the Lower group of Dr. Sandberger) contained many species of shells common to the Limburg beds near Kleyn Spawen, and to the clay of Rupelmonde, near Antwerp. Among these he mentioned *Cassidaria depressa*, *Tritonium argutum*, Brander (*T. flandricum*, De Koninck), *Tornatella simulata*, *Rostellaria Sowerbyi*, *Leda Deshayesiana* (fig. 167. p. 189.), *Corbula pisum* (fig. 170.), and *Pectunculus terebratularis.*

The marine beds are in some places covered with brackish-water marls containing *Cyrenæ* in great numbers, among which *Cyrena semistriata* occurs, with *Cerithium plicatum*. *Corbulomya triangula*, *Mytilus Fanjasii*, and other Limburg and Hempstead shells. *Perna Soldani*, a shell of the upper Eocene or Mérignac beds of the Bordeaux basin, but also a Vienna basin shell, is characteristic both of the marine and brackish series. Two species of Anthracotherium, *A. magnum*, Cuv., and *A. alsaticum*, are met with in the same deposits.

The upper portion of this Mayence series has at its base a limestone full of *Cerithia* and land-shells; among which *Cerithium plicatum* before mentioned, and another Limburg shell, *Venus incrassata*, Sow., a fossil common to the Headon or *Middle* Eocene of England, are met with; also *Neritina concava* (fig. 194.), a Middle Eocene shell, and *Rhinoceros incisivus*, the oldest form of that genus, and called by Kaup *Acerotherium*. Next above is a limestone, in which *Littorinella* or *Paludina inflata* is a very common fossil, with others of the same genus. One of these, very nearly resembling the recent *Littorinella ulva*, is found throughout this basin. These shells are like grains of rice in size, and are often in such quantity as to form entire beds of marl and limestone, in stratified masses from fifteen to thirty feet in thickness, just as in the Baltic modern accumulations several feet thick of the *Littorinella ulva* are spread far and wide over the bottom of the sea. In the same beds, several species of *Dreissena* abound, a form common to the Headon or Middle Eocene beds of the Isle of Wight, as well as to the existing seas. On the whole, I am not satisfied that this fauna diverges from the Limburg type towards that of the faluns as much as Dr. Sandberger believes. Among the Mammalia, we find *Hippotherium gracile*, *Acerotherium* (or *Rhinoceros*) *incisivum*, *Paleomeryx*, *Cha-*

Fig. 168.

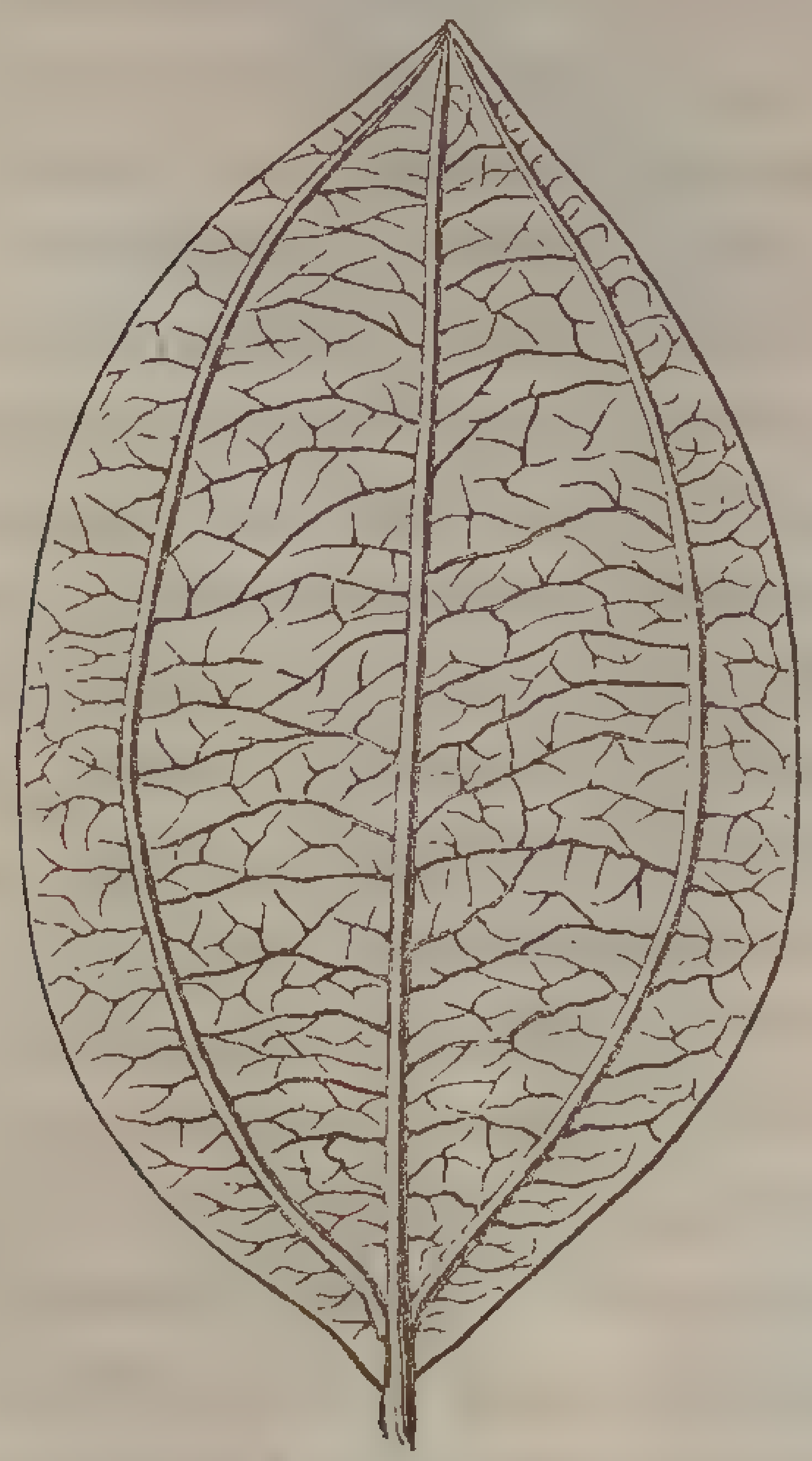
Paludina. Mayence.

licomys, &c. Lastly, the Eppelsheim sand overlies the whole, containing *Deinotherium giganteum*, and some other true Miocene quadrupeds. Several mammalia, proper to the Upper Eocene series, are also said to be associated; but there being no good section at Eppelsheim, the true succession of the beds from which the bones were dug out cannot be seen, and we have yet to learn whether some remains of an older series may not have been confounded with those of a newer one.

Brown coal of Germany. — In a recent essay on the Brown Coal deposits of Germany, Baron Von Buch has expressed a decided opinion that they all belong to one epoch, being of subsequent date to the great nummulitic period, and newer than the Pliocene formations. He has therefore called the whole Miocene. Unfortunately, these formations rarely contain any internal evidence of their age, except what may be derived from plants, constituting in every case but a fraction of an ancient Flora, and consisting of mere leaves, without flowers or fruits. It is often therefore impossible to form more than a conjecture as to the precise place in the chronological series which should be assigned to each layer of lignite or each leaf-bed. Nevertheless, enough is known to show that some of the Brown Coals found in isolated patches belong to the Upper Eocene, others to the Miocene, and some perhaps to the Pliocene eras. They seem to have been formed at a period when the European area had already a somewhat continental character, so that few contemporaneous marine or even fluvio-marine beds were in progress there.

The brown coal of Brandenburg, on the borders of the Baltic, underlies the Hermsdorf tile-clay already spoken of, and therefore belongs to a period at least as old as the Upper Eocene. The brown coal of Radoboj, on the confines of Styria, is covered, says Von Buch, by beds containing the marine shells of the Vienna basin, which, as before remarked, are chiefly of the Falunian or Miocene type. This lignite, therefore, may be of Miocene or Upper Eocene date, a point to be determined by the botanical characters of the plants. In this, and most of the principal brown coal formations, several species of fan-palm or *Flabellaria* abound. This genus also appears in the Middle Eocene or Bembridge beds in the Isle of Wight, and in the gypseous series of Montmartre; but it is still more largely represented in the Upper Eocene series, accompanied by palms of the genus *Phœnicites*. Various cones, and the leaves and wood of coniferous trees, are also met with at Radoboj. Species also of *Comptonia* and *Myrica*, with various trees, such as the plane or *Platanus*, are recognized by their leaves, as also

Fig. 169.



Daphnogene cinnamomifolia, Altsattel, in Bohemia.

several of the Laurel tribe, especially one, called *Daphnogene cinnamomifolia* (fig. 169.) by Unger, who, together with Göppert, has investigated the botany of these formations. It will be seen that in the leaf of this *Daphnogene* two veins branch off on each side from the mid-rib, and run up without interruption to the point.

On the Lower Rhine, whether in the Mayence basin or in the Siebengebirge, and in the neighbourhood of Bonn and Cologne, there seem to be Brown Coals of more than one age. Von Buch tells us that the only fossil found in the Brown Coal near Cologne, one often met with there in the excavation of a tunnel, is the peculiar fruit, so like a cocoa-nut, called *Nipadites* or *Burtonia Fanjasii* (see fig. 220.). Now this fossil abounds in the Lower Eocene or Sheppy clay near London, also in the Middle Eocene at Brussels; and I found it still higher in the same nummulitic series at Cassel, in French Flanders. This fact taken alone would rather lead us to refer the Cologne lignite to the Eocene period.

Some of the lignites of the Siebengebirge near Bonn associated with volcanic rocks, and those of Hesse Cassel which accompany basaltic outpourings, are certainly of much later date.

UPPER EOCENE STRATA OF ENGLAND.

Hempstead beds.—Isle of Wight.—Until very lately it was supposed by English geologists that the newest tertiary strata of the Isle of Wight corresponded in age with the gypseous series of Montmartre near Paris; and this idea was confirmed by the fact that the same species of *Palæotherium*, *Anoplotherium*, and other extinct mammalia so characteristic of the Parisian series, were also found at Binstead, near Ryde, in the northern district of the island, forming part of the fluvio-marine series. We are indebted to Prof. E. Forbes for having discovered in the autumn of 1852 that there exist three formations, the true position of which had been overlooked, all of them newer than the beds of Headon Hill, in Alum Bay, which last were formerly believed to be the uppermost part of the Isle of Wight tertiary series.*

The three overlying formations to which I allude are as follows:—1st, certain shales and sandstones called the St. Helen's beds (see Table, p. 105. *et seq.*) rest immediately upon the Headon series; 2dly, the St. Helen's series is succeeded by the Bembridge beds before mentioned, the equivalent of the Montmartre gypsum; and 3rdly, above the whole is found the Upper Eocene or Hempstead series. This newer deposit, which is 170 feet thick, has been so called from Hempstead Hill, near Yarmouth, in the Isle of Wight.† The following is the succession of strata there discovered, the details of which are important for reasons explained in the preliminary remarks of this chapter (p. 188.):—

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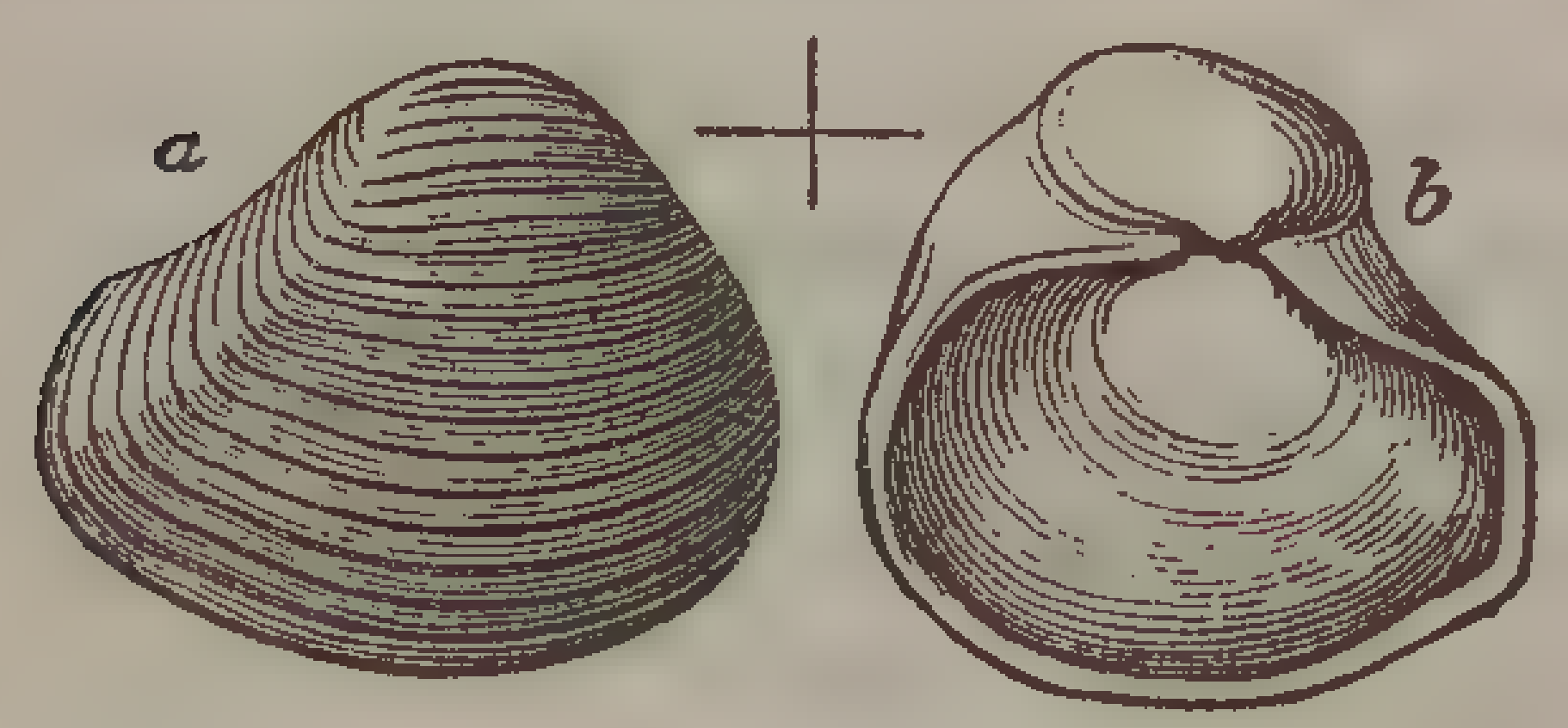
* E. Forbes, Geol. Quart. Journ. 1853.

† This hill must not be confounded with Hampstead Hill, near London, where the Lower Eocene or London Clay is capped by Middle Eocene sands.

SUBDIVISIONS OF THE HEMPSTEAD SERIES.

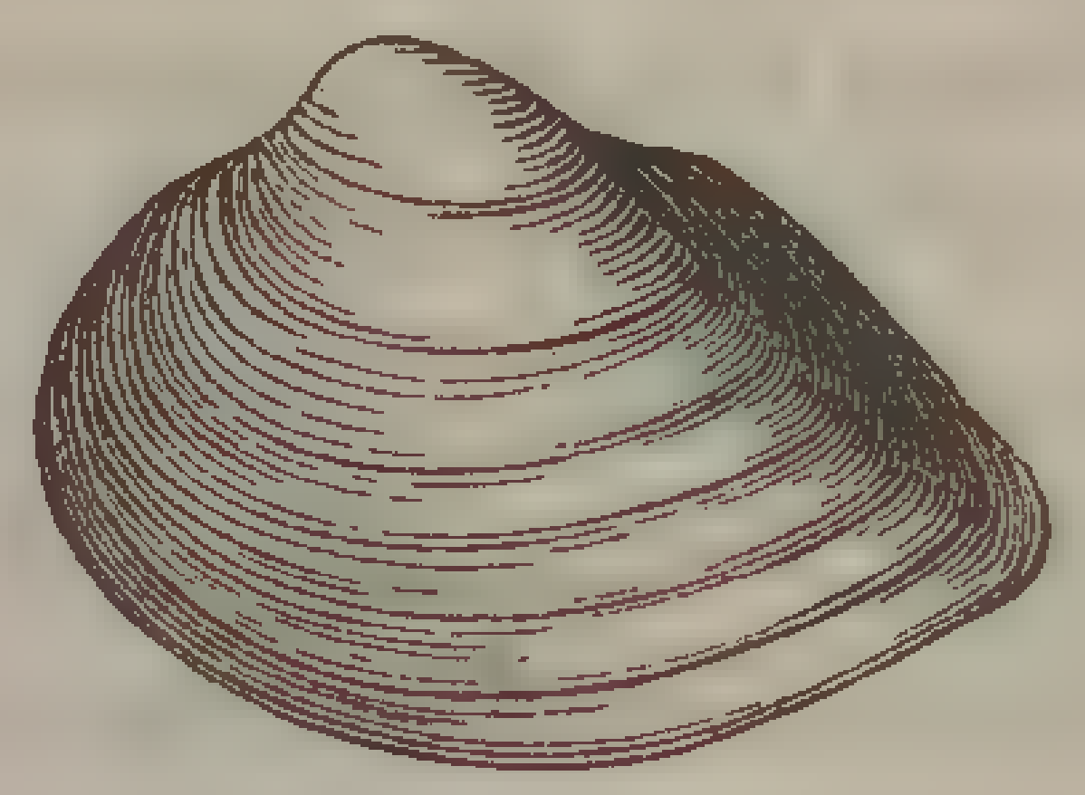
1. The uppermost or Corbula beds, consisting of marine sands and clays, contain *Corbula pisum*, fig. 170., a species common to the Middle Eocene clay of Barton; *Cyrena semistriata*, fig. 171., which is also a Middle Eocene fossil; several *Cerithia*, and other shells peculiar to this series.

Fig. 170.



Corbula pisum. Hempstead Beds, Isle of Wight.

Fig. 171.



Cyrena semistriata. Hempstead Beds.

2. Next below are freshwater and estuary marls and carbonaceous clays, in the brackish-water portion of which are found abundantly *Cerithium plicatum*, Lam., fig. 172., *C. elegans*, fig. 173., and *C. tricinctum*; also *Rissoa Chastelii*, fig. 174., a very common Limburg shell, and which occurs in each of the four subdivisions of the Hempstead series down to its base, where it passes into the Bembridge beds. In the freshwater portion of the same beds *Paludina lenta*, fig. 175., occurs, a shell identified by some conchologists with a species now living, *P. unicolor*; also several species of *Lymneus*, *Planorbis*, and *Unio*.

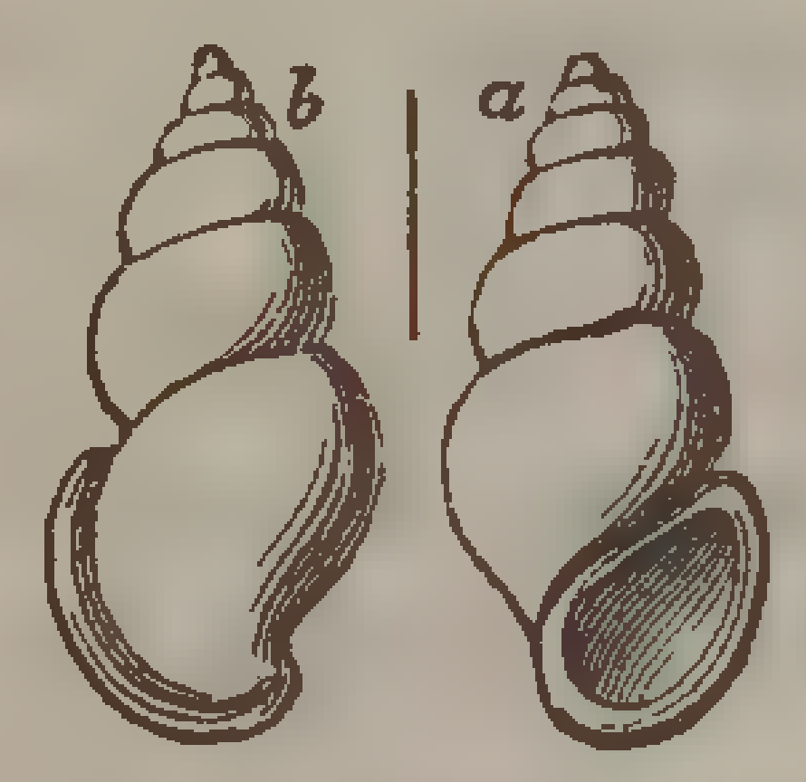
Fig. 172.

Cerithium plicatum, Lam. Hempstead.

Fig. 173.

Cerithium elegans. Hempstead.

Fig. 174.



Rissoa Chastelii, Nyst, Sp. Hempstead, Isle of Wight.

Fig. 175.

Paludina lenta. Hempstead Beds.

3. The next series, or middle freshwater and estuary marls, are distinguished by the presence of *Melania fasciata*, *Paludina lenta*, and clays with *Cypris*; the lowest bed contains *Cyrena semistriata*, fig. 171., mingled with *Cerithia* and a *Panopæa*.

4. The lower freshwater and estuary marls contain *Melania costata*, Sow., *Melanopsis*, &c. The bottom bed is carbonaceous, and called the "Black band," in which *Rissoa Chastelii*, fig. 173., before alluded to, is common. This bed contains a mixture of Hempstead shells with those of the underlying Middle Eocene or Bembridge series. The seed-vessels of *Chara medicaginula*, Brong., and *C. helecteras* are characteristic of the Hempstead beds generally. The mammalia, among which is a species of *Hyotherium*, differ, so far as they are known, from those of the Bembridge beds immediately underlying.

Between the Hempstead beds above described and those next below them, there is no break, as before stated, p. 188. The freshwater, brackish, and marine limestones and marls of the underlying or Bembridge group are in conformable stratification, and contain *Cyrena semistriata*, fig. 171., *Melania muricata*, *Paludina lenta*, fig. 175., and several other shells belonging to the Hempstead beds. Prof. Forbes therefore classes both of them in the same Upper Eocene division. I have called the Bembridge beds Middle Eocene, for convenience sake, as already explained (pp. 184. 188.).

UPPER EOCENE STRATA OF FRANCE.

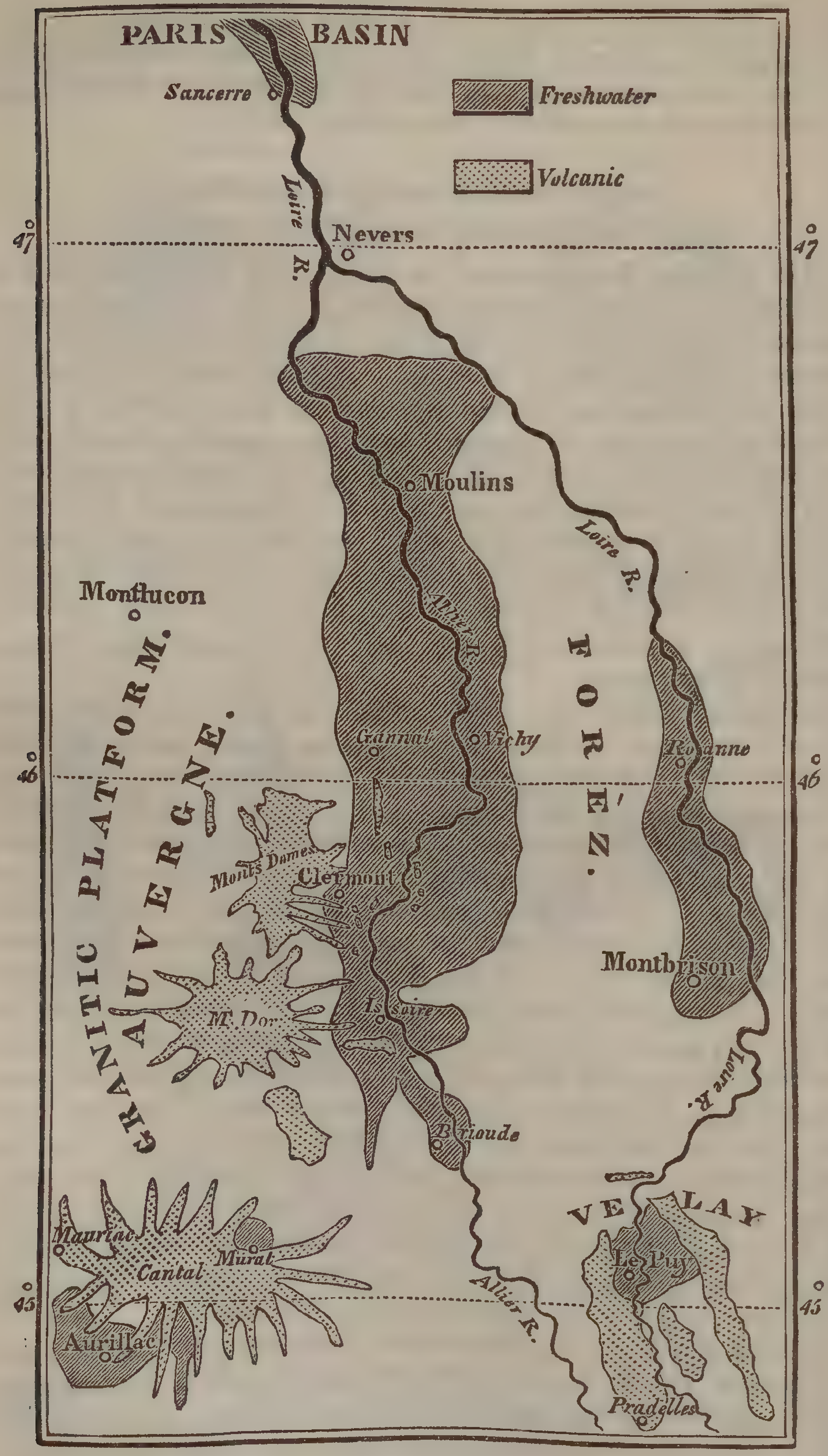
(*Lower Miocene of many French authors.*)

The Grès de Fontainebleau, or sandstone of the Forest of Fontainebleau, has been frequently alluded to in the preceding pages, as corresponding in age to the Limburg or Hempstead beds. It is associated in the suburbs of Paris with a set of strata, very varied in their composition, and containing in their lower portion a green clay with abundance of small oysters (*Ostrea cyathula*, Lam.) which are spread over a wide area. The marine sands and sandstone which overlie this clay include *Cytherea incrassata* and many other Limburg fossils, the finest collections of which have been made at Etampes, south of Paris, where they occur in loose sand. The Grès de Fontainebleau is sometimes called the "Upper marine sands" to distinguish it from the "Middle sands" or Grès de Beauchamp, a Middle Eocene group.

Calcaire lacustre supérieur.—Above the Grès de Fontainebleau is seen the upper freshwater limestone and marl, sometimes called Calcaire de la Beauce, which with its accompanying marls and siliceous beds seem to have been formed in marshes and shallow lakes, such as frequently overspread the newest parts of great deltas. Beds of flint, continuous or in nodules, accumulated in these lakes, and *Charæ*, aquatic plants, already alluded to, left their stems and seed-vessels imbedded both in the marl and flint, together with freshwater and land-shells. Some of the siliceous rocks of this formation are used extensively for millstones. The flat summits or platforms of the hills round Paris—large areas in the forest of Fontainebleau, and the Plateau de la Beauce, between the Seine and the Loire, are chiefly composed of these upper freshwater strata. When they reach the valley of the Loire, they occasionally underlie and form the boundary of the marine Miocene faluns, fragments of the older freshwater limestone having been broken off and rolled on the shores and in the bed of the Miocene sea, as at Pontlevoy, on the Cher, where the perforating marine shells of the Miocene period still remain in hollows drilled in the blocks of Eocene limestone.

Central France.—Lacustrine strata, belonging, for the most part, to the same Upper Eocene series, are again met with in Auvergne, Cantal, and Velay, the sites of which may be seen in the annexed map. They appear to be the monuments of ancient lakes, which, like some of those now existing in Switzerland, once occupied the depressions in a mountainous region, and have been each fed by one

Fig. 176.



or more rivers and torrents. The country where they occur is almost entirely composed of granite and different varieties of granitic schist, with here and there a few patches of secondary strata, much dislocated, and which have probably suffered great denudation. There are also some vast piles of volcanic matter (see the map), the greater part of which is newer than the freshwater strata, and is sometimes seen to rest upon them, while a small part has evidently been of contemporaneous origin. Of these igneous rocks I shall treat more particularly in another part of this work.

Before entering upon any details, I may observe that the study of these regions possesses a peculiar interest, very distinct in kind from that derivable from the investigation either of the Parisian or English tertiary areas. For we are presented in Auvergne with the evidence of a series of events of astonishing magnitude and grandeur, by which the original form and features of the country have been greatly changed, yet never so far obliterated but that they may still, in part at least, be restored in imagination. Great lakes have disappeared, — lofty mountains have been formed, by the reiterated emission of lava, preceded and followed by showers of sand and scoriæ, — deep valleys have been subsequently furrowed out through masses of lacustrine and volcanic origin, — at a still later date, new cones have been thrown up in these valleys, — new lakes have been formed by the damming up of rivers,—and more than one creation of quadrupeds, birds, and plants, Eocene, Miocene, and Pliocene, have followed in succession; yet the region has preserved from first to last its geographical identity; and we can still recall to our thoughts its external condition and physical structure before these wonderful vicissitudes began, or while a part only of the whole had been completed. There was first a period when the spacious lakes, of which we still may trace the boundaries, lay at the foot of mountains of moderate elevation, unbroken by the bold peaks and precipices of Mont Dor, and unadorned by the picturesque outline of the Puy de Dome, or of the volcanic cones and craters now covering the granitic platform. During this earlier scene of repose deltas were slowly formed; beds of marl and sand, several hundred feet thick, deposited; siliceous and calcareous rocks precipitated from the waters of mineral springs; shells and insects imbedded, together with the remains of the crocodile and tortoise; the eggs and bones of water birds, and the skeletons of quadrupeds, some of them belonging to the same genera as those entombed in the Eocene gypsum of Paris. To this tranquil condition of the surface succeeded the era of volcanic eruptions, when the lakes were drained, and when the fertility of the mountainous district was probably enhanced by the igneous matter ejected from below, and poured down upon the more sterile granite. During these eruptions, which appear to have taken place after the disappearance of the Upper Eocene fauna, and partly in the Miocene epoch, the mastodon, rhinoceros, elephant, tapir, hippopotamus, together with the ox, various kinds of deer, the bear, hyæna, and many beasts of prey ranged the forest, or pastured on the plain, and were occasionally overtaken by a fall of burning cinders, or buried in flows of mud, such as accompany volcanic eruptions. Lastly, these quadrupeds became extinct, and gave place to Pliocene mammalia (see ch. xxxii.), and these, in their turn, to species now existing. There are no signs, during the whole time required for this series of events, of the sea having intervened, nor of any denudation which may not have been accomplished by currents in the different lakes, or by rivers and floods accompanying repeated earthquakes, during which the levels of the district have in some places been materially modified, and perhaps the whole upraised relatively to the surrounding parts of France.

Auvergne.—The most northern of the freshwater groups is situated in the valley-plain of the Allier, which lies within the department of the Puy de Dome, being the tract which went formerly by the name of the Limagne d'Auvergne. It is inclosed by two parallel mountain ranges,—that of the Forèz, which divides the waters of the Loire and Allier, on the east; and that of the Monts Domes, which separates the Allier from the Sioule, on the west.* The average breadth of this tract is about 20 miles; and it is for the most part composed of nearly horizontal strata of sand, sandstone, calcareous marl, clay, and limestone, none of which observe a fixed and invariable order of superposition. The ancient borders of the lake, wherein the freshwater strata were accumulated, may generally be traced with precision, the granite and other ancient rocks rising up boldly from the level country. The actual junction, however, of the lacustrine and granitic beds is rarely seen, as a small valley usually intervenes between them. The freshwater strata may sometimes be seen to retain their horizontality within a very slight distance of the border-rocks, while in some places they are inclined, and in few instances vertical. The principal divisions into which the lacustrine series may be separated are the following:—1st, Sandstone, grit, and conglomerate, including red marl and red sandstone; 2dly, Green and white foliated marls; 3dly, Limestone or travertin, often oolitic; 4thly, Gypseous marls.

1. *a. Sandstone and conglomerate.*—Strata of sand and gravel, sometimes bound together into a solid rock, are found in great abundance around the confines of the lacustrine basin, containing, in different places, pebbles of all the ancient rocks of the adjoining elevated country; namely, granite, gneiss, mica-schist, clay-slate, porphyry, and others, but without any intermixture of basaltic or other tertiary volcanic rocks. These strata do not form one continuous band around the margin of the basin, being rather disposed like the independent deltas which grow at the mouths of torrents along the borders of existing lakes.

At Chamalieres, near Clermont, we have an example of one of these deltas, or littoral deposits, of local extent, where the pebbly beds slope away from the granite, as if they had formed a talus beneath the waters of the lake near the steep shore. A section of about 50 feet in vertical height has been laid open by a torrent, and the pebbles are seen to consist throughout of rounded and

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* Scrope, Geology of Central France, p. 15.

angular fragments of granite, quartz, primary slate, and red sandstone. Partial layers of lignite and pieces of wood are found in these beds.

At some localities on the margin of the basin quartzose grits are found ; and, where these rest on granite, they are sometimes formed of separate crystals of quartz, mica, and felspar, derived from the disintegrated granite, the crystals having been subsequently bound together by a siliceous cement. In these cases the granite seems regenerated in a new and more solid form ; and so gradual a passage takes place between the rock of crystalline and that of mechanical origin, that we can scarcely distinguish where one ends and the other begins.

In the hills called the Puy de Jussat and La Roche, we have the advantage of seeing a section continuously exposed for about 700 feet in thickness. At the bottom are foliated marls, white and green, about 400 feet thick ; and above, resting on the marls, are the quartzose grits, cemented by calcareous matter, which is sometimes so abundant as to form imbedded nodules. These sometimes constitute spheroidal concretions 6 feet in diameter, and pass into beds of solid limestone, resembling the Italian travertins, or the deposits of mineral springs.

1. *b. Red marl and sandstone.*—But the most remarkable of the arenaceous groups is one of red sandstone and red marl, which are identical in all their mineral characters with the secondary *New Red sandstone* and marl of England. In these secondary rocks the red ground is sometimes variegated with light greenish spots, and the same may be seen in the tertiary formation of freshwater origin at Coudes, on the Allier. The marls are sometimes of a purplish-red colour, as at Champheix, and are accompanied by a reddish-limestone, like the well-known "cornstone," which is associated with the Old Red sandstone of English geologists. The red sandstone and marl of Auvergne have evidently been derived from the degradation of gneiss and mica-schist, which are seen *in situ* on the adjoining hills, decomposing into a soil very similar to the tertiary red sand and marl. We also find pebbles of gneiss, mica-schist, and quartz in the coarser sandstones of this group, clearly pointing to the parent rocks from which the sand and marl are derived. The red beds, although destitute themselves of organic remains, pass upwards into strata containing tertiary fossils, and are certainly an integral part of the lacustrine formation. From this example the student will learn how small is the value of mineral character alone, as a test of the relative age of rocks.

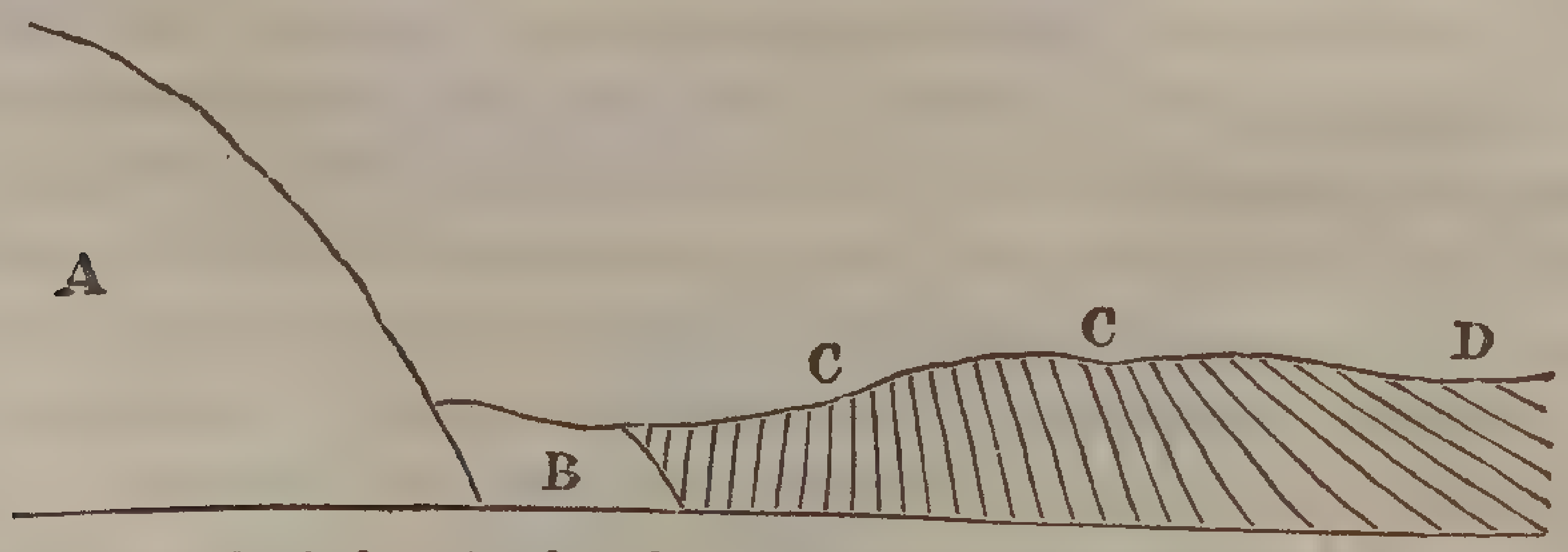
2. *Green and white foliated marls.*—The same primary rocks of Auvergne, which, by the partial degradation of their harder parts, gave rise to the quartzose grits and conglomerates before mentioned, would, by the reduction of the same materials into powder, and by the decomposition of their felspar, mica, and hornblende, produce aluminous clay, and, if a sufficient quantity of carbonate of lime was present, calcareous marl. This fine sediment would naturally

be carried out to a greater distance from the shore, as are the various finer marls now deposited in Lake Superior. And as, in the American lake, shingle and sand are annually amassed near the northern shores, so in Auvergne the grits and conglomerates before mentioned were evidently formed near the borders.

The entire thickness of these marls is unknown; but it certainly exceeds, in some places, 700 feet. They are, for the most part, either light-green or white, and usually calcareous. They are thinly foliated,—a character which frequently arises from the innumerable thin shells, or carapace-valves, of that small animal called *Cypris*. This animal is provided with two small valves, not unlike those of a bivalve shell, and moults its integuments periodically, which the conchiferous mollusks do not. This circumstance may partly explain the countless myriads of the shells of *Cypris* which were shed in the ancient lakes of Auvergne, so as to give rise to divisions in the marl as thin as paper, and that, too, in stratified masses several hundred feet thick. A more convincing proof of the tranquillity and clearness of the waters, and of the slow and gradual process by which the lake was filled up with fine mud, cannot be desired. But we may easily suppose that, while this fine sediment was thrown down in the deep and central parts of the basin, gravel, sand, and rocky fragments were hurried into the lake, and deposited near the shore, forming the group described in the preceding section.

Not far from Clermont, the green marls, containing the *Cypris* in abundance, approach to within a few yards of the granite which forms the borders of the basin. The occurrence of these marls so near the ancient margin may be explained by considering that, at the bottom of the ancient lake, no coarse ingredients were deposited in spaces intermediate between the points where rivers and torrents entered, but finer mud only was drifted there by currents. The *verticality* of some of the beds in the above section bears testimony to considerable local disturbance subsequent to the deposition of the marls; but such inclined and vertical strata are very rare.

Fig. 177.



Vertical strata of marl, at Champradelle, near Clermont.

A. Granite.
B. Space of 60 feet, in which no section is seen.
C. Green marl, vertical and inclined.
D. white marl.

3. *Limestone, travertin, oolite.*—Both the preceding members of the lacustrine deposit, the marls and grits, pass occasionally into limestone. Sometimes only concretionary nodules abound in them; but these, where there is an increase in the quantity of calcareous matter, unite into regular beds.

On each side of the basin of the Limagne, both on the west at Gannat, and on the east at Vichy, a white oolitic limestone is quarried. At Vichy, the oolite resembles our Bath stone in appearance and beauty; and, like it, is soft when first taken from the quarry, but soon hardens on exposure to the air. At Gannat, the stone contains land-shells and bones of quadrupeds. At Chadrat, in the hill of La Serre, the limestone is pisolitic, the small spheroids combining both the radiated and concentric structure.

Indusial limestone.—There is another remarkable form of freshwater limestone in Auvergne, called "indusial," from the cases, or *indusiæ*, of caddis-worms (the larvæ of *Phryganea*); great heaps of which have been incrusted, as they lay, by carbonate of lime, and formed into a hard travertin. The rock is sometimes purely calcareous, but there is occasionally an intermixture of siliceous matter. Several beds of it are frequently seen, either in continuous masses, or in concretionary nodules, one upon another, with layers of marl interposed. The annexed drawing (fig. 178.) will show the manner in which one of these indusial beds (*a*) is laid open at the surface, between the marls (*b b*), near the base of the hill of Gergovia; and affords, at the same time, an example of the extent to which the lacustrine strata, which must once have filled a hollow, have been denuded, and shaped out into hills and valleys, on the site of the ancient lakes.

Fig. 178.

Bed of indusial limestone, interstratified with freshwater marl, near Clermont (Kleinschrod).

We may often observe in our ponds the *Phryganea* (or Caddis-fly), in its caterpillar state, covered with small freshwater shells, which they have the power of fixing to the outside of their tubular cases, in order, probably, to give them weight and strength. The individual figured in the annexed cut, which belongs to a species very abundant in England, has covered its case with shells of a small *Planorbis.* In the same manner a large species of caddis-worm which swarmed in the Eocene lakes of Auvergne was accustomed to attach to its dwelling the shells of a small spiral univalve of the genus *Paludina.* A hundred of these minute shells are sometimes seen arranged around one tube, part of the central cavity of which is often empty, the rest being filled up with thin concentric layers of travertin. The cases have been thrown together confusedly, and often lie, as in fig. 180., at right angles one to the other. When we consider that ten or twelve tubes are packed within the compass of a cubic inch, and that some single strata of this limestone are 6 feet thick, and may be traced over a considerable area, we may form some idea of the countless number of insects and mollusca which contributed their integuments and shells to compose this singularly constructed rock. It is unnecessary to suppose that the *Phryganeæ* lived on the spots where their cases are now found; they may have multiplied in the shallows near the margin of the lake, or in the streams by which it was fed, and their cases may have been drifted by a current far into the deep water.

Fig. 179.

Larva of recent *Phryganea.**

Fig. 180.

a. Indusial limestone of Auvergne. *b.* Fossil *Paludina* magnified.

In the summer of 1837, when examining, in company with Dr. Beck, a small lake near Copenhagen, I had an opportunity of witnessing a beautiful exemplification of the manner in which the tubular cases of Auvergne were probably accumulated. This lake, called the Fuure-Soe, occurring in the interior of Seeland, is about twenty English miles in circumference, and in some parts 200 feet in depth. Round the shallow borders an abundant crop of reeds and rushes may be observed, covered with the indusiæ of the *Phryganea grandis* and other species, to which shells are attached. The plants which support them are the bulrush, *Scirpus lacustris,* and common reed, *Arundo phragmites,* but chiefly the former. In summer, especially in the month of June, a violent gust of wind sometimes causes a current by which these plants are torn up by the roots, washed away, and floated off in long bands, more than a mile in length, into deep water. The *Cypris* swarms in the same lake; and calcareous springs

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* I believe that the British specimen here figured is *P. rhombica,* Linn.

alone are wanting to form extensive beds of indusial limestone, like those of Auvergne.

4. *Gypseous marls.* — More than 50 feet of thinly laminated gypseous marls, exactly resembling those in the hill of Montmartre, at Paris, are worked for gypsum at St. Romain, on the right bank of the Allier. They rest on a series of green cypridiferous marls which alternate with grit, the united thickness of this inferior group being seen, in a vertical section on the banks of the river, to exceed 250 feet.

General arrangement, origin, and age of the freshwater formations of Auvergne. — The relations of the different groups above described cannot be learnt by the study of any one section; and the geologist who sets out with the expectation of finding a fixed order of succession may perhaps complain that the different parts of the basin give contradictory results. The arenaceous division, the marls, and the limestone may all be seen in some places to alternate with each other; yet it can by no means be affirmed that there is no order of arrangement. The sands, sandstone, and conglomerate constitute in general a littoral group; the foliated white and green marls, a contemporaneous central deposit; and the limestone is for the most part subordinate to the newer portions of both. The uppermost marls and sands are more calcareous than the lower; and we never meet with calcareous rocks covered by a considerable thickness of quartzose sand or green marl. From the resemblance of the limestones to the Italian travertins, we may conclude that they were derived from the waters of mineral springs, — such springs as even now exist in Auvergne, and which may be seen rising up through the granite, and precipitating travertin. They are sometimes thermal, but this character is by no means constant.

It seems that, when the ancient lake of the Limagne first began to be filled with sediment, no volcanic action had yet produced lava and scoriæ on any part of the surface of Auvergne. No pebbles, therefore, of lava were transported into the lake,—no fragments of volcanic rocks embedded in the conglomerate. But at a later period, when a considerable thickness of sandstone and marl had accumulated, eruptions broke out, and lava and tuff were deposited, at some spots, alternately with the lacustrine strata. It is not improbable that cold and thermal springs, holding different mineral ingredients in solution, became more numerous during the successive convulsions attending this development of volcanic agency, and thus deposits of carbonate and sulphate of lime, silex, and other minerals were produced. Hence these minerals predominate in the uppermost strata. The subterranean movements may then have continued until they altered the relative levels of the country, and caused the waters of the lakes to be drained off, and the farther accumulation of regular freshwater strata to cease.

We may easily conceive a similar series of events to give rise to analogous results in any modern basin, such as that of Lake Superior, for example, where numerous rivers and torrents are carrying down the detritus of a chain of mountains into the lake. The transported materials must be arranged according to their size and weight, the coarser near the shore, the finer at a greater distance from land; but in the gravelly and sandy beds of Lake Superior no pebbles of modern volcanic rocks can be included, since there are none of these at present in the district. If igneous action should break out in that country, and produce lava, scoriæ, and thermal springs, the deposition of gravel, sand, and marl might still continue as before; but, in addition, there would then be an intermixture of volcanic gravel and tuff, and of rocks precipitated from the waters of mineral springs.

Although the freshwater strata of the Limagne approach generally to a horizontal position, the proofs of local disturbance are sufficiently numerous and violent to allow us to suppose great changes of level since the lacustrine period. We are unable to assign a northern barrier to the ancient lake, although we can still trace its limits to the east, west, and south, where they were formed of bold granite eminences. Nor need we be surprised at our inability to restore entirely the physical geography of the country after so great a series of volcanic eruptions; for it is by no means improbable that one part of it, the southern, for example, may have been moved upwards bodily, while others remained at rest, or even suffered a movement of depression.

Whether all the freshwater formations of the Limagne d'Auvergne belong to one period, I cannot pretend to decide, as large masses both of the arenaceous and marly groups are often devoid of fossils. Some of the oldest or lowest sands and marls may very probably be of Middle Eocene date. Much light has been thrown on the mammiferous fauna by the labours of MM. Bravard and Croizet, and by those of M. Pomel. The last-mentioned naturalist has pointed out the specific distinction of all, or nearly all, the species of mammalia from those of the gypseous series near Paris, although many of the forms are analogous to those of Eocene quadrupeds. The *Cainotherium*, for example, is not far removed from the *Anoplotherium*, and is, according to Waterhouse, the same as the genus *Microtherium* of the Germans. There are two species of marsupial animals allied to *Didelphys*, a genus also found in the Paris gypsum, and several forms of ruminants of extinct genera, such as *Amphitragulus elegans* of Pomel, which has been identified with a Rhenish species from Weissenau near Mayence, called by Kaup *Dorcatherium nanum;* other associated fossils, e. g., *Microtherium Reuggeri*, and a small rodent, *Titanomys*, are also specifically the same with mammalia of the Mayence basin. The *Hyænodon*, a remarkable carnivorous genus, is represented by more than one species, and the oldest representative of the genus *Machairodus* has been discovered in these beds in Auvergne. The first of these, *Hyænodon*, also occurs in the English Middle-Eocene marls of Hordwell cliff, Hampshire, considerably below the level of the Bembridge limestone, with Paleotheria. Upon the whole it is clear that a large portion of the Limagne rocks have been correctly referred by French geologists to their Middle Tertiary, and to that part of it which is called Upper Eocene in this work.

Cantal.—A freshwater formation, of about the same age and very analogous to that of Auvergne, is situated in the department of Haute Loire, near the town of Le Puy, in Velay; and another occurs near Aurillac, in Cantal. The leading feature of the formation last mentioned, as distinguished from those of Auvergne and Velay, is the immense abundance of silex associated with calcareous marls and limestone.

The whole series may be separated into two divisions; the lower, composed of gravel, sand, and clay, such as might have been derived from the wearing down and decomposition of the granitic schists of the surrounding country; the upper system, consisting of siliceous and calcareous marls, contains subordinately gypsum, silex, and limestone.

The resemblance of the freshwater limestone of the Cantal, and its accompanying flint, to the upper chalk of England, is very instructive, and well calculated to put the student upon his guard against relying too implicitly on mineral character alone as a safe criterion of relative age.

When we approach Aurillac from the west, we pass over great heathy plains, where the sterile mica-schist is barely covered with vegetation. Near Ytrac, and between La-Capelle and Viscamp, the surface is strewed over with loose broken flints, some of them black in the interior, but with a white external coating; others stained with tints of yellow and red, and in appearance precisely like the flint gravel of our chalk districts. When heaps of this gravel have thus announced our approach to a new formation, we arrive at length at the escarpment of the lacustrine beds. At the bottom of the hill which rises before us, we see strata of clay and sand, resting on mica-schist; and above, in the quarries of Belbet, Leybros, and Bruel, a white limestone, in horizontal strata, the surface of which has been hollowed out into irregular furrows, since filled up with broken flint, marl, and dark vegetable mound. In these cavities we recognize an exact counterpart to those which are so numerous on the furrowed surface of our own white chalk. Advancing from these quarries along a road made of the white limestone, which reflects as glaring a light in the sun as do our roads composed of chalk, we reach, at length, in the neighbourhood of Aurillac, hills of limestone and calcareous marl, in horizontal strata, separated in some places by regular layers of flint in nodules, the coating of each nodule being of an opaque white colour, like the exterior of the flinty nodules of our chalk.

The abundant supply both of siliceous, calcareous, and gypseous matter, which the ancient lakes of France received, may have been connected with the subterranean volcanic agency of which those regions were so long the theatre, and which may have impregnated the springs with mineral matter, even before the great outbreak of lava. It is well known that the hot springs of Iceland, and many other countries, contain silex in solution; and it has been lately affirmed, that steam at a high temperature is capable of dissolving quartzose rocks without the aid of any alkaline or other flux.* Warm water charged with siliceous matter would immediately part with a portion of its silex, if its temperature was lowered by mixing with the cooler waters of a lake.

A hasty observation of the white limestone and flint of Aurillac might convey the idea that the rock was of the same age as the white chalk of Europe; but when we turn from the mineral aspect and composition to the organic remains, we find in the flints of the Cantal seed-vessels of the freshwater *Chara*, instead of the marine zoophytes so abundant in chalk flints; and in the limestone we meet with shells of *Limnea*, *Planorbis*, and other lacustrine genera.

Proofs of gradual deposition.—Some sections of the foliated marls in the valley of the Cer, near Aurillac, attest, in the most unequivocal manner, the extreme slowness with which the materials of the lacustrine series were amassed. In the hill of Barrat, for example, we find an assemblage of calcareous and siliceous marls; in which, for a depth of at least 60 feet, the layers are so thin, that thirty are sometimes contained in the thickness of an inch; and when they are separated, we see preserved in every one of them the flattened stems of *Charæ*, or other plants, or sometimes myriads of small *Paludinæ* and other freshwater shells. These minute foliations of the marl resemble precisely some of the recent laminated beds of the Scotch marl lakes, and may be compared to the pages of a book, each containing a history of a certain period of the past. The different layers may be grouped together in beds from a foot to a foot and a half in thickness, which are distinguished by differences of composition and colour, the tints being white, green, and brown. Occasionally there is a parting layer of pure flint, or of black carbonaceous vegetable matter, about an inch thick, or of white pulverulent marl. We find several hills in the neighbourhood of Aurillac composed of such materials, for the height of more than 200 feet from their base, the whole sometimes covered by rocky currents of trachytic or basaltic lava.†

Thus wonderfully minute are the separate parts of which some of the most massive geological monuments are made up! When we desire to classify, it is necessary to contemplate entire groups of strata in the aggregate; but if we wish to understand the mode of their formation, and to explain their origin, we must think only of the minute subdivisions of which each mass is composed. We must bear in mind how many thin leaf-like seams of matter, each containing the remains of myriads of testacea and plants, frequently enter into the composition of a single stratum, and how vast a succession of these strata unite to form a single group! We must remember, also, that piles of volcanic matter, like the Plomb du Cantal, which rises in the immediate neighbourhood of Aurillac, are themselves equally

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* See Proceedings of Royal Soc., No. 44. p. 233.

† Lyell and Murchison, sur les Dépôts Lacustres Tertiaires du Cantal, &c. Ann. des Sci. Nat. Oct. 1829.

the result of successive accumulation, consisting of reiterated sheets of lava, showers of scoriæ, and ejected fragments of rock.—Lastly, we must not forget that continents and mountain-chains, colossal as are their dimensions, are nothing more than an assemblage of many such igneous and aqueous groups, formed in succession during an indefinite lapse of ages, and superimposed upon each other.

Bordeaux, Aix, &c.—The Upper Eocene strata in the Bordeaux basin are represented, according to M. Raulin, by the Falun de Leognan, and the underlying limestone of St. Macaire. By many, however, the upper of these, or the Leognan beds, are considered to be no older than the faluns of Touraine. The freshwater strata of Aix-en-Provence are probably Upper Eocene; also the tertiary rocks of Malta, Crete, Cerigo, and those of many parts of Greece and other countries bordering the Mediterranean.

Nebraska, United States.—In the territory of Nebraska, on the Upper Missouri, near the Platte River, lat. 42° N., a tertiary formation occurs, consisting of white limestone, marls, and siliceous clay, described by Dr. D. Dale Owen*, in which many bones of extinct quadrupeds, and of chelonians of land or freshwater forms, are met with. Among these, Dr. Leidy recognizes a gigantic *Palæotherium*, larger than any of the Parisian species; several species of the genus *Orcodon*, Leidy, uniting the characters of pachyderms and ruminants; *Eucrotaphus*, another new genus of the same mixed character; two species of rhinoceros of the sub-genus *Acerotherium*, an Upper Eocene form of Europe before mentioned; two of *Archæotherium*, a pachyderm allied to *Chœropotamus* and *Hyracotherium;* also *Pœbrotherium*, an extinct ruminant allied to *Dorcatherium*, Kaup; also *Agriochœgus* of Leidy, a ruminant allied to *Merycopotamus* of Falconer and Cautley; and, lastly, a large carnivorous animal of the genus *Macairodus*, the most ancient example of which in Europe occurs in the Upper Eocene beds of Auvergne. The turtles are referred to the genus *Testudo*, but have some affinity to *Emys*. On the whole, this formation has, I believe, been correctly referred by American writers to the Eocene period, in conformity with the classification adopted by me, but would, I conceive, be called Lower Miocene by those who apply that term to all strata newer than the Paris gypsum.

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* David Dale Owen, Geol. Survey of Wisconsin, &c.: Philad. 1852.

CHAPTER XVI.

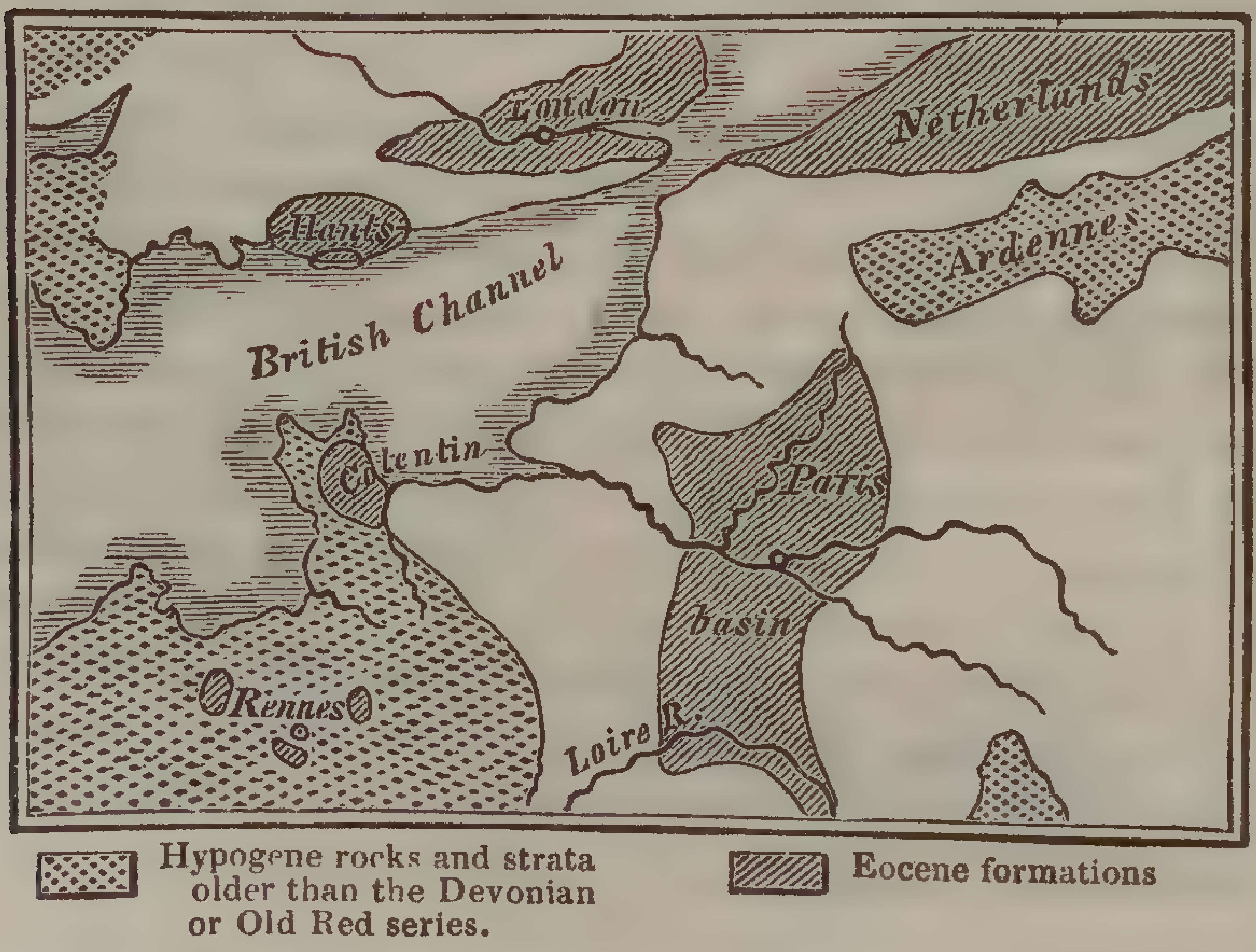
MIDDLE AND LOWER EOCENE FORMATIONS.

Middle Eocene strata of England—Fluvio-marine series in the Isle of Wight and Hampshire—Successive groups of Eocene Mammalia—Fossils of Barton Clay—Shells, nummulites, fishes, and reptiles of the Bagshot and Bracklesham beds—Lower Eocene strata of England—Fossil plants and shells of the London Clay proper—Strata of Kyson in Suffolk—Fossil monkey and opossum—Plastic clays and sands—Thanet sands—Middle Eocene formations of France—Gypseous series of Montmartre and extinct quadrupeds—Calcaire grossier—Miliolites—Lower Eocene in France—Nummulitic formations of Europe and Asia—Their wide extent—referable to the Middle Eocene period—Eocene strata in the United States—Section at Claiborne, Alabama—Colossal cetacean—Orbitoid limestone—Burr stone.

The strata next in order in the descending series are those which I term Middle Eocene. In the accompanying map, the position of several Eocene areas is pointed out, such as the basin of the Thames, part of Hampshire, part of the Netherlands, and the country round Paris. The three last-mentioned areas contain some marine and freshwater formations, which have been already spoken of as Upper Eocene, but their superficial extent in this part of Europe is insignificant.

Fig. 181.

Map of the principal tertiary basins of the Eocene period.



N.B. The space left blank is occupied by secondary formations from the Devonian or old red sandstone to the chalk inclusive.

ENGLISH MIDDLE EOCENE FORMATIONS.

The following table will show the order of succession of the strata found in the Tertiary areas, commonly called the London and Hampshire basins. (See also Table, p. 105. *et seq.*)

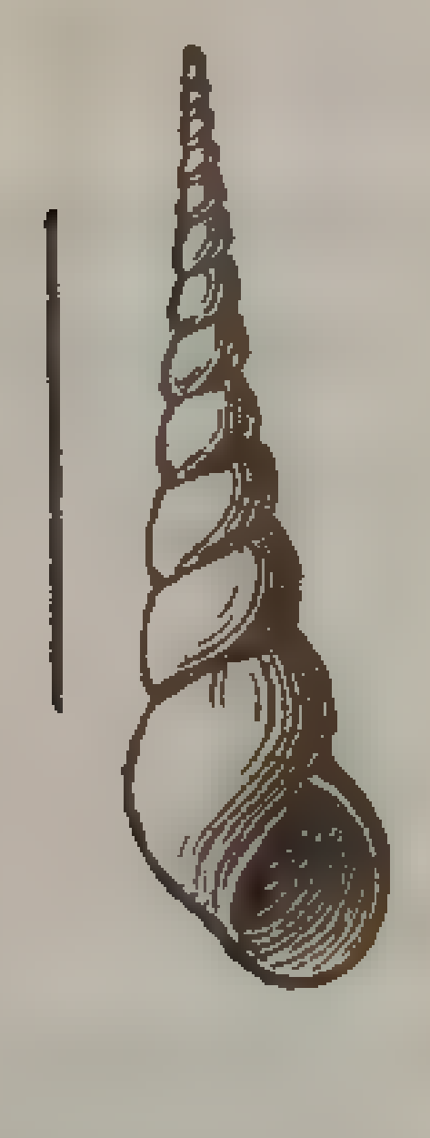
		Thickness.
	UPPER EOCENE.	
A.	Hempstead beds, Isle of Wight, see above, p. 193.	170 feet.
	MIDDLE EOCENE.	
B. 1.	Bembridge Series, — North coast of Isle of Wight	120
B. 2.	Osborne or St. Helen's Series, — ibid.	100
B. 3.	Headon Series, — Isle of Wight, and Hordwell Cliff, Hants	170
B. 4.	Headon Hill sands and Barton Clay, — Isle of Wight, and Barton Cliff, Hants	300
B. 5.	Bagshot and Bracklesham Sands and Clays, — London and Hants basins	700
	LOWER EOCENE.	
C. 1.	London Clay proper and Bognor beds, — London and Hants basins	350 to 500
C. 2.	Plastic and Mottled Clays and Sands (Woolwich and Reading series), — London and Hants basins	100
C. 3.	Thanet Sands, — Reculvers, Kent, and Eastern part of London basin	90

The true place of the Bagshot sands, B. 5. in the above series, and of the Thanet sands, C. 3., was first accurately ascertained by Mr. Prestwich in 1847 and 1852. The true relative position of the Hempstead beds, A., of the Bembridge, B. 1., and of the Osborne or St. Helen's series, B. 2., were not made out in a satisfactory manner till Professor Forbes studied them in detail in 1852.

Bembridge series, B. 1. — These beds are above 100 feet thick, and, as before stated (p. 188.), pass upwards into the Hempstead beds, with which they are conformable, near Yarmouth, in the Isle of Wight. They consist of marls, clays, and limestones of freshwater, brackish, and marine origin. Some of the most abundant shells, as *Cyrena semistriata* var., and *Paludina lenta*, fig. 175. p. 194., are common to this and to the overlying Hempstead series. The following are the subdivisions described by Professor Forbes: —

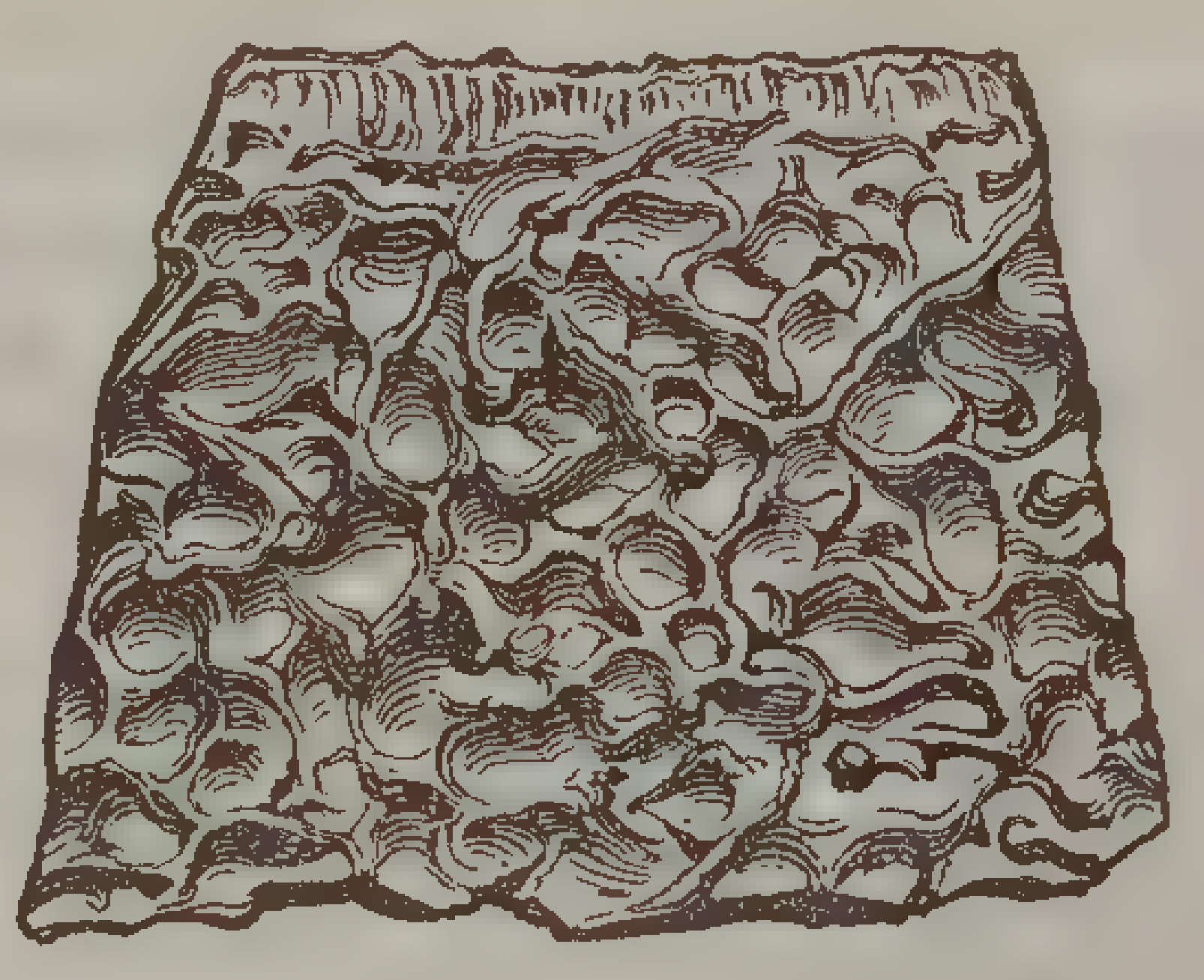
a. Upper marls, distinguished by the abundance of *Melania turritissima*, Forbes (fig. 182.).

Fig. 182.



Melania turritissima, Forbes.
Bembridge.

Fig. 183.



Fragment of Carapace of *Trionyx*.
Bembridge Beds, Isle of Wight.

b. Lower marl, characterized by *Cerithium mutabile*, *Cyrena pulchra*, &c., and by the remains of *Trionyx* (see fig. 183.).

c. Green marls, often abounding in a peculiar species of oyster, and accompanied by *Cerithia*, *Mytili*, an *Arca*, a *Nucula*, &c.

d. Bembridge limestones, compact cream-coloured limestones alternating with shales and marls, in all of which land-shells are common, especially at Sconce, near Yarmouth, and have been described by Mr. Edwards. The *Bulimus ellipticus*, fig. 184., and *Helix occlusa*, fig. 185., are among its best known land-shells. *Paludina orbicularis*, fig. 186., is also of frequent occurrence. One of the bands is filled with a little globular *Paludina*. Among the freshwater pulmonifera, *Lymnea longiscata* (fig. 188.) and *Planorbis discus* (fig. 187.) are the most generally distributed: the latter represents or takes the place of the *Planorbis euomphalus* (see fig. 192.), of the more ancient Headon series. *Chara tuberculata* (fig. 189.) is the characteristic Bembridge gyrogonite.

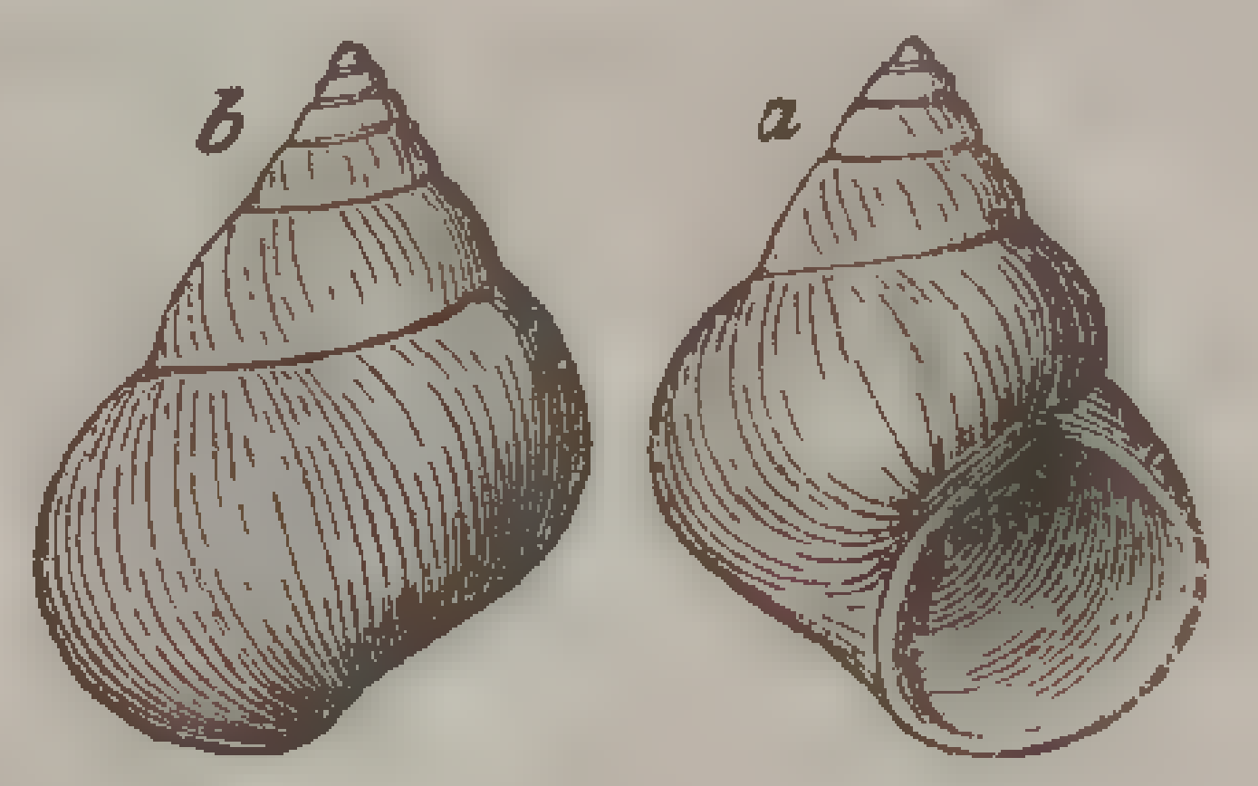
Fig. 184.

Bulimus ellipticus, Sow.
Bembridge Limestone,
half natural size.

Fig. 185.

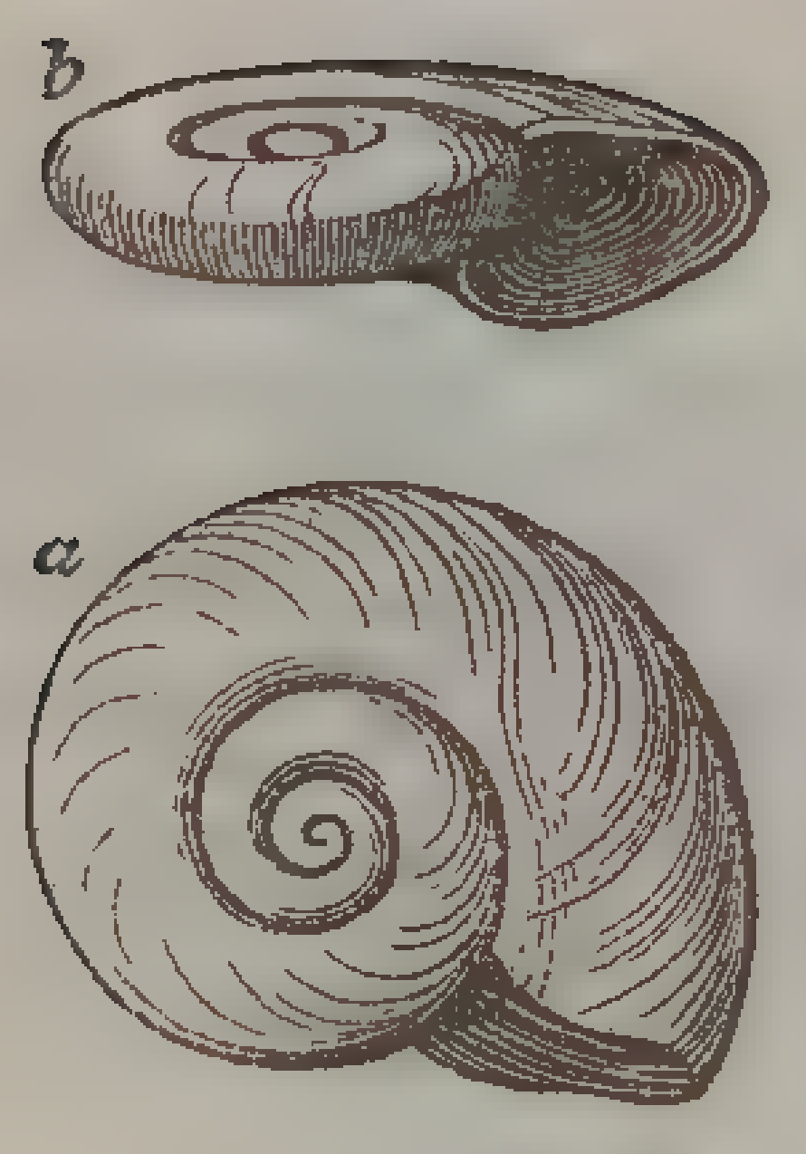
Helix occlusa, Edwards,
Sconce Limestone,
Isle of Wight.

Fig. 186.



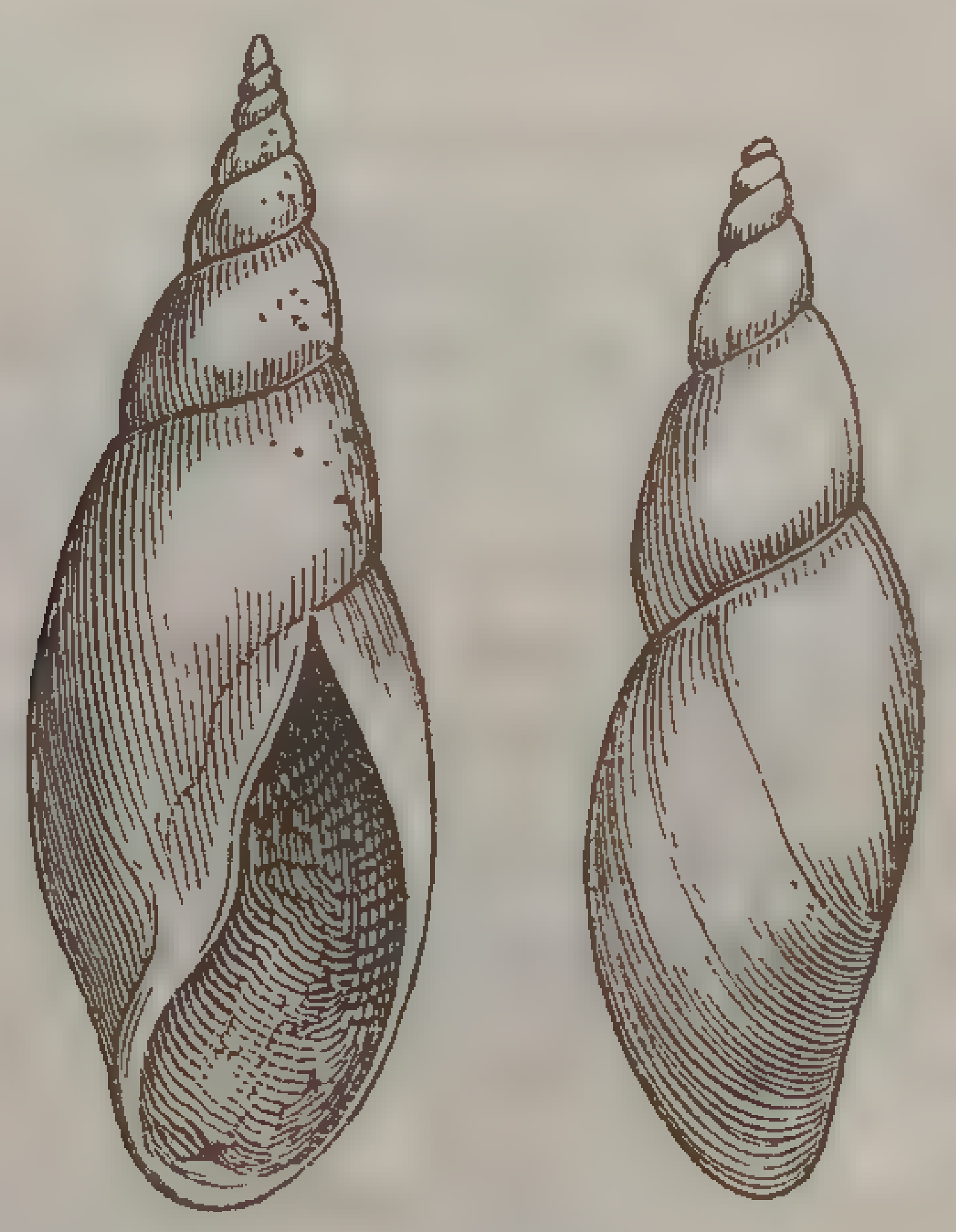
Paludina orbicularis. Bembridge.

Fig. 187.



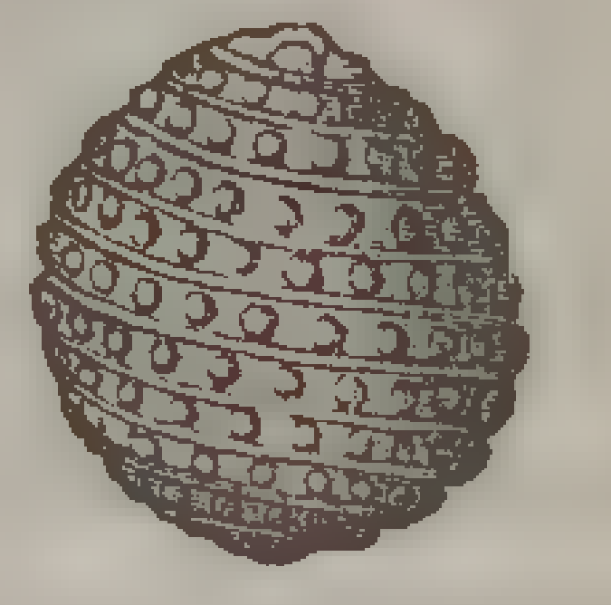
Planorbis discus, Edwards. Bembridge. ½ diam.

Fig. 188.



Lymnea longiscata, Brard.

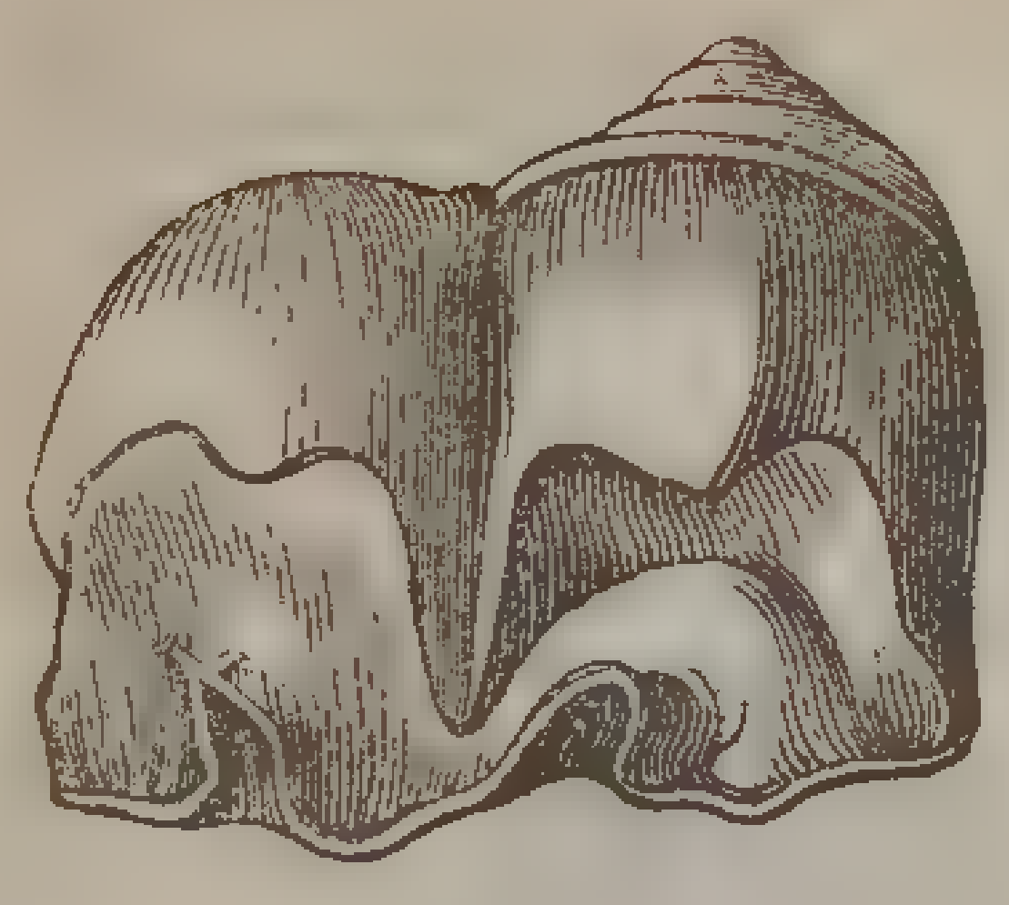
Fig. 189.



Chara tuberculata.
Bembridge Limestone, I. of Wight.

From this formation on the shores of Whitecliff Bay, Dr. Mantell obtained a fine specimen of a fan palm, *Flabellaria Lamanonis*, Brong., a plant first obtained from beds of corresponding age in the suburbs of Paris. The well-known building-stone of Binstead, near Ryde, a limestone with numerous hollows caused by *Cyrenæ* which have disappeared and left the moulds of their shells, belongs to this subdivision of the Bembridge series. In the same Binstead stone Mr. Pratt and the Rev. Darwin Fox first discovered the remains of mammalia characteristic of the gypseous series of Paris, as *Palæotherium*

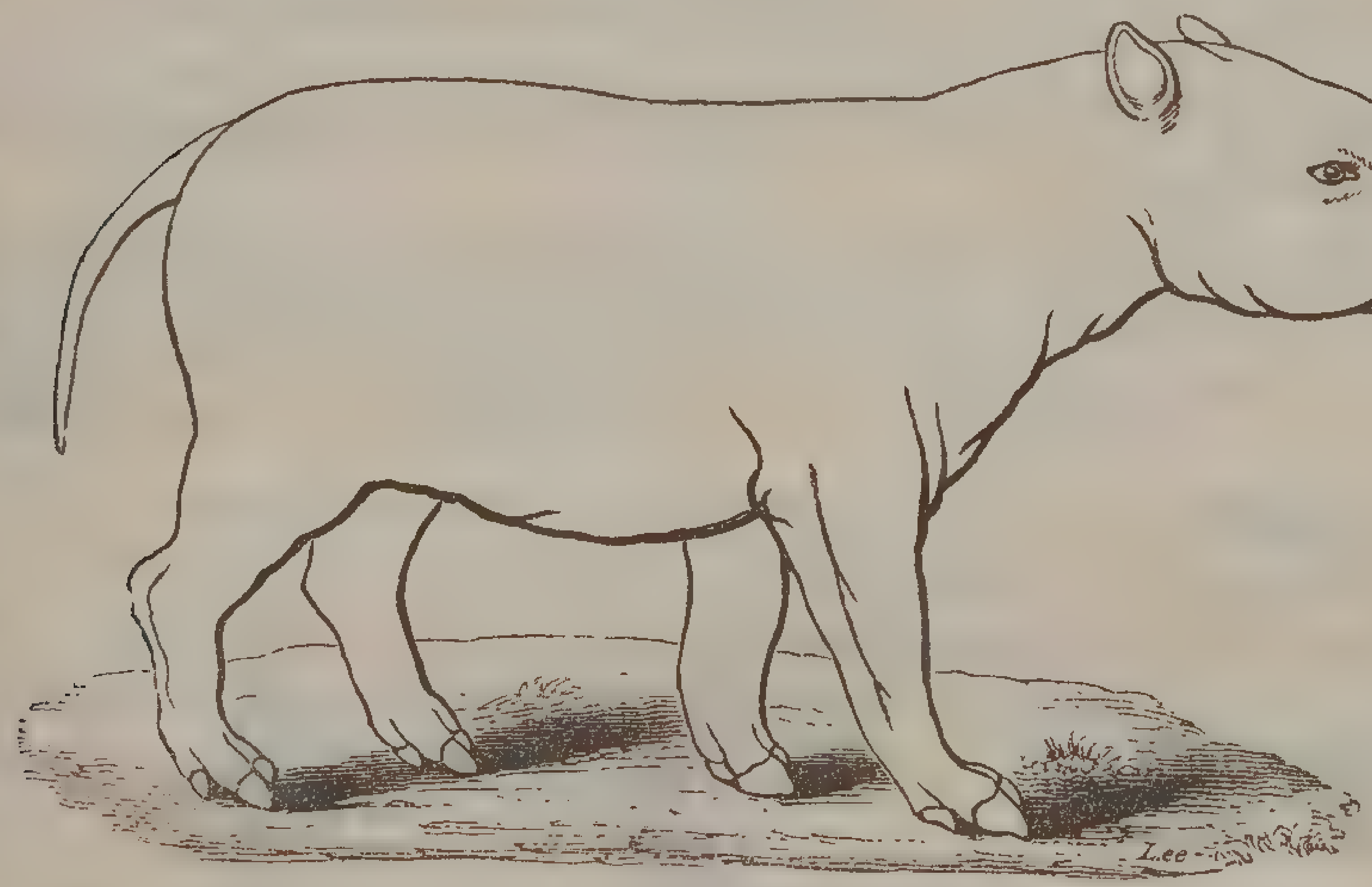
Fig. 190.



Lower Molar tooth, nat. size, *Anoplotherium commune.* Binstead, Isle of Wight.

magnum, (fig. 191.) *P. medium*, *P. minus*, *P. mimimum*, *P. curtum*, *P. crassum*; also *Anoplotherium commune* (fig. 190.), *A. secundarium*, *Dichobune cervinum*, and *Chæropotamus Cuvieri.* The genus Paleothere, above alluded to, resembled the living tapir in the form of the head, and in having a short proboscis, but its molar teeth were more like those of the rhinoceros (see fig. 190.). *Paleotherium magnum* was of the size of a horse, three or four feet high. The annexed woodcut, fig. 191., is one of the restorations which Cuvier attempted of the outline of the living animal, derived from the study of the entire skeleton. As the vertical range of particular species of quadrupeds, so far as our knowledge extends, is far more limited than that of the testacea; the occurrence of so many species at Binstead, agreeing with fossils of the Paris gypsum, strengthens the evidence derived from shells and plants of the synchronism of the two formations.

Fig. 191.

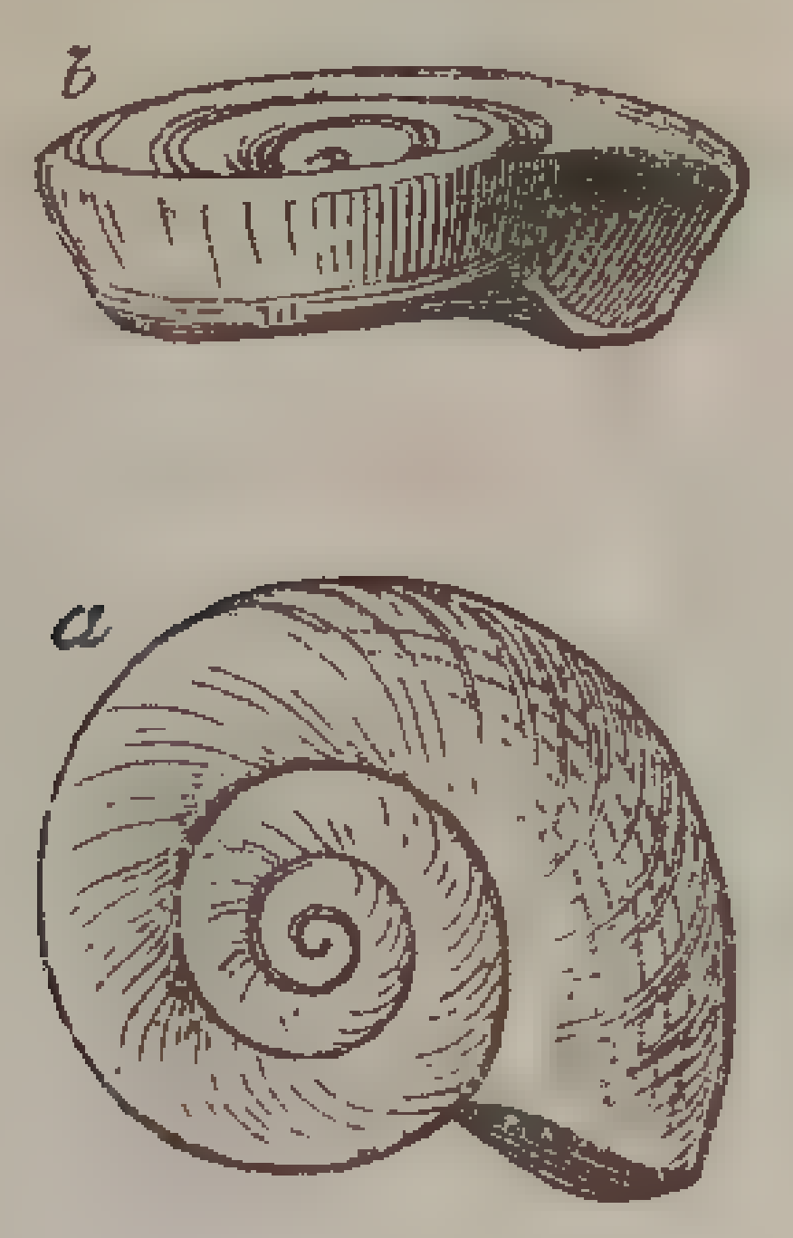


Paleotherium magnum, Cuvier.

Osborne or St. Helen's series, B. 2. — This group is of fresh and brackish-water origin, and very variable in mineral character and thickness. Near Ryde, it supplies a freestone much used for building, and called by Prof. Forbes the Nettlestone grit. In one part ripple-marked flag-stones occur, and rocks with fucoidal markings. The Osborne beds are distinguished by peculiar species of *Paludina*, *Melania*, and *Melanopsis*, as also of *Cypris* and the seeds of *Chara*.

Headon series, B. 3. — These beds are seen both at the east and west extremities of the Isle of Wight, and also in Hordwell Cliffs, Hants. Everywhere *Planorbis euomphalus*, fig. 192., characterizes the freshwater deposits, just as the allied form, *P. discus*, fig. 187., does the Bembridge limestone. The brackish-water beds contain *Potomomya plana*, *Cerithium mutabile*, and *C. cinctum* (fig. 44. p. 30.), and the marine beds *Venus* (or *Cytherea*) *incrassata*, a species common to the Limburg beds and Grès de Fontainebleau, or the Upper Eocene series. The prevalence of salt-water remains is most conspicuous in some of the central parts of the formation. Mr. T. Webster, in his able memoirs on the Isle of Wight, first separated the whole into a lower freshwater, an upper marine, and an upper freshwater division.

Fig. 192.



Planorbis euomphalus, Sow.
Headon Hill. ½ diam.

Fig. 193.

Helix labyrinthica, Say. Headon Hill, Isle of Wight; and Hordwell Cliff, Hants—also recent.

Among the shells which are widely distributed through the Headon series are *Neritina concava*, (fig.194.), *Lymnea caudata* (fig. 195.), and *Cerithium concavum* (fig. 196.). *Helix labyrinthica*, Say (fig. 193.), a land-shell now inhabiting the United States, was discovered in this series by Mr. Wood in Hordwell Cliff. It is also met with in Headon Hill, in the same beds. At Sconce, in the Isle of Wight, it occurs in the newer Bembridge series, and affords a rare example of an Eocene fossil of a species still living, though, as usual in such cases, having no local connexion with the actual geographical range of the species.

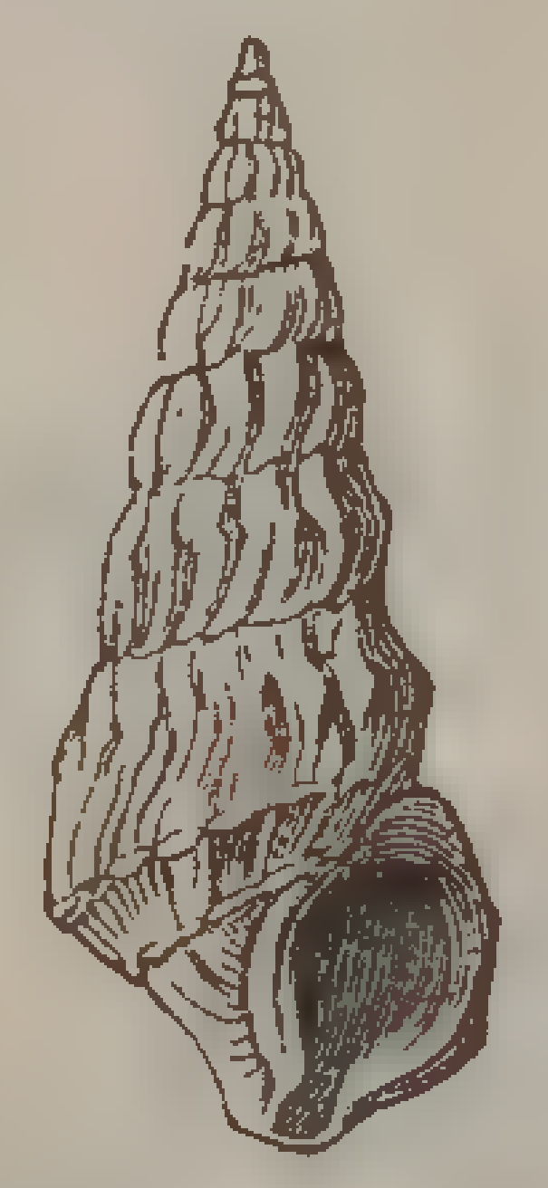
Fig. 194.

Neritina concava.
Headon Series.

Fig. 195.

Lymnea caudata.
Headon Beds.

Fig. 196.



Cerithium concavum
Headon Series.

The lower and middle portion of the Headon series is also met with in Hordwell Cliff (or Hordle, as it is often spelt), near Lymington, Hants, where the organic remains have been studied by Mr. Searles Wood, Dr. Wright, and the Marchioness of Hastings. To the latter we are indebted for a detailed section of the beds *, as well as for the discovery of a variety of new species of fossil mammalia, chelonians, and fish; also for first calling attention to the important fact that these vertebrata differ specifically from those of the Bembridge beds. Among the abundant shells of Hordwell are *Paludina lenta* and various species of *Lymneus, Planorbis, Melania, Cyclas*, and *Unio, Potomomya, Dreissena*, &c.

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* Bulletin Soc. Géol. de France, 1852, p. 191.

Among the chelonians we find a species of *Emys*, and no less than six species of *Trionyx;* among the saurians an alligator and a crocodile; among the ophidians two species of land-snakes (*Paleryx*, Owen); and among the fish Sir P. Egerton and Mr. Wood have found the jaws, teeth, and hard shining scales of the genus *Lepidosteus* or bony pike of the American rivers. This same genus of freshwater ganoids has also been met with in the Hempstead beds in the Isle of Wight. The bones of several birds have been obtained from Hordwell, and the remains of quadrupeds. The latter belong to the genera *Paloplotherium* of Owen, *Anoplotherium*, *Anthracotherium*, *Dichodon* of Owen (a new genus discovered by Mr. A. H. Falconer), *Dichobune*, *Spalacodon*, and *Hyænodon*. The latter offers, I believe, the oldest known example of a true carnivorous mammal in the series of British fossils, although I attach very little theoretical importance to the fact, because herbivorous species are those most easily met with in a fossil state in all save cavern deposits. In another point of view, however, this fauna deserves notice. Its geological position is considerably lower that that of the Bembridge or Montmartre beds, from which it differs almost as much in species as it does from the still more ancient fauna of the Lower Eocene beds to be mentioned in the sequel. It therefore teaches us what a grand succession of distinct assemblages of mammalia flourished on the earth during the Eocene period.

Many of the marine shells of the brackishwater beds of the above series, both in the Isle of Wight and Hordwell Cliff, are common to the underlying Barton clay; and, on the other hand, there are some freshwater shells, such as *Cyrena obovata*, which are common to the Bembridge beds, notwithstanding the intervention of the St. Helen's series. The white and green marls of the Headon series, and some of the accompanying limestones, often resemble the Eocene strata of France in mineral character and colour in so striking a manner, as to suggest the idea that the sediment was derived from the same region or produced contemporaneously under very similar geographical circumstances.

Both in Hordwell Cliff and in the Isle of Wight, the Headon beds rest on white sands, the upper member of the Barton series, B. 4., next to be mentioned.

Headon Hill sands and Barton clay, B. 4. (Table, p. 209.) — In one of the upper and sandy beds of this formation Dr. Wright found *Chama squamosa* in great plenty. The same sands contain impressions of many marine shells (especially in Whitecliff Bay) common to the upper Bagshot sands afterwards to be described. The underlying Barton clay has yielded about 209 marine shells, more than half of them, according to Mr. Prestwich, peculiar; and only eleven common to the London clay proper, (C.1. p. 209.,) being in the proportion of only 5 per cent. On the other hand, 70 of them agree with the shells of the *calcaire grossier* of France. It is nearly a century

Fig. 197.

Chama squamosa.
Barton.

since Brander published, in 1766, an account of the organic remains collected from these Barton and Hordwell cliffs, and his excellent figures of the shells then deposited in the British Museum are justly admired by conchologists for their accuracy.

SHELLS OF THE BARTON CLAY, HANTS.

Certain foraminifera called Nummulites begin, when we study the tertiary formations in a descending order, to make their first appearance in these Barton beds. A small species called *Nummulites variolaria* is found both on the Hampshire coast and in beds of the same age in Whitecliff Bay, in the Isle of Wight. Several marine shells, such as *Corbula pisum*, are common to the Barton beds and the Hempstead or Upper Eocene series, and a still greater number, as before stated, are common to the Headon series.

Fig. 198.

Mitra scabra.

Fig. 199.

Voluta ambigua.

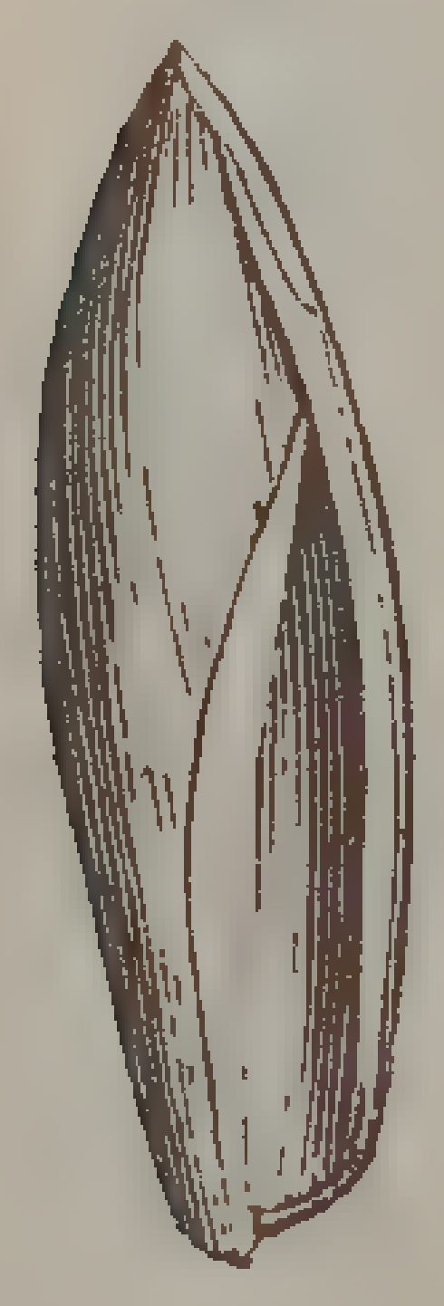
Fig. 200.

Typhis pungens.

Fig. 201.

Voluta athleta. Barton and Braklesham.

Fig. 202.



Terebellum fusiforme. Barton and Bracklesham.

Fig. 203.

Terebellum convolutum, Lam. *Seraphs convolutum*, Montf.

Fig. 204.

Cardita globosa.

Fig. 205.

Crassatella sulcata.

Bagshot and Bracklesham beds, B. 5.—The Bagshot beds, consisting chiefly of siliceous sand, occupy extensive tracts round Bagshot, in Surrey, and in the New Forest, Hampshire. They may be separated into three divisions, the upper and lower consisting of light yellow sands, and the central of dark green sands and brown clays, the whole reposing on the London clay proper.* The uppermost division is probably of about the same age as the Barton series. Although

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* Prestwich, Quart. Geol. Journ. vol. iii. p. 386.

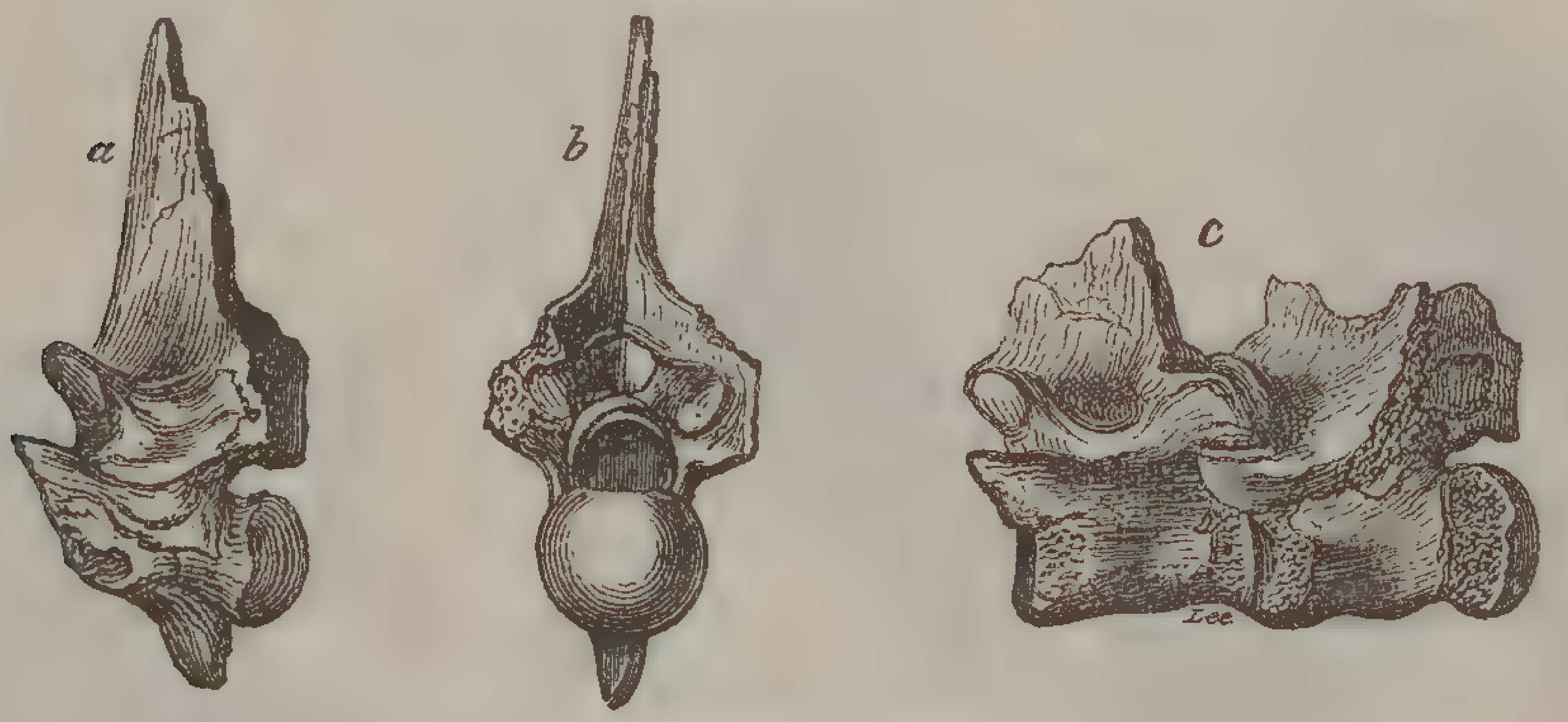
the Bagshot beds are usually devoid of fossils, they contain marine shells in some places, among which *Venericardia planicosta* (see fig. 206.) is abundant, with *Turritella sulcifera* and *Nummulites lævigata.* (See fig. 210. p. 216.).

Fig. 206.

Venericardia planicosta, Lam.
Cardita planicosta, Deshayes.

At Bracklesham Bay, near Chichester, in Sussex, the characteristic shells of this member of the Eocene series are best seen; among others, the huge *Cerithium giganteum*, so conspicuous in the calcaire grossier of Paris, where it is sometimes 2 feet in length. The volutes and cowries of this formation, as well as the lunulites and corals, seem to favour the idea of a warm climate having prevailed, which is borne out by the discovery of a serpent, *Palæophis typhæus* (see fig. 207.), exceeding, according to Prof. Owen, 20 feet in length, and allied in its osteology to the Boa, Python, Coluber, and Hydrus. The compressed form and diminutive size of certain caudal vertebræ indicate so much analogy with Hydrus as to induce the Hunterian professor to pronounce this extinct ophidian to have been marine.* He had previously combated with much success the evidence advanced to prove the existence in the Northern Ocean of huge sea-serpents in our own times, but he now contends for the former existence in the British Eocene seas, of less gigantic serpents,

Fig. 207.



Palæophis typhæus, Owen; an Eocene sea-serpent. Bracklesham.
a. b. vertebra, with long neural spine preserved. *c.* two vertebræ in natural articulation.

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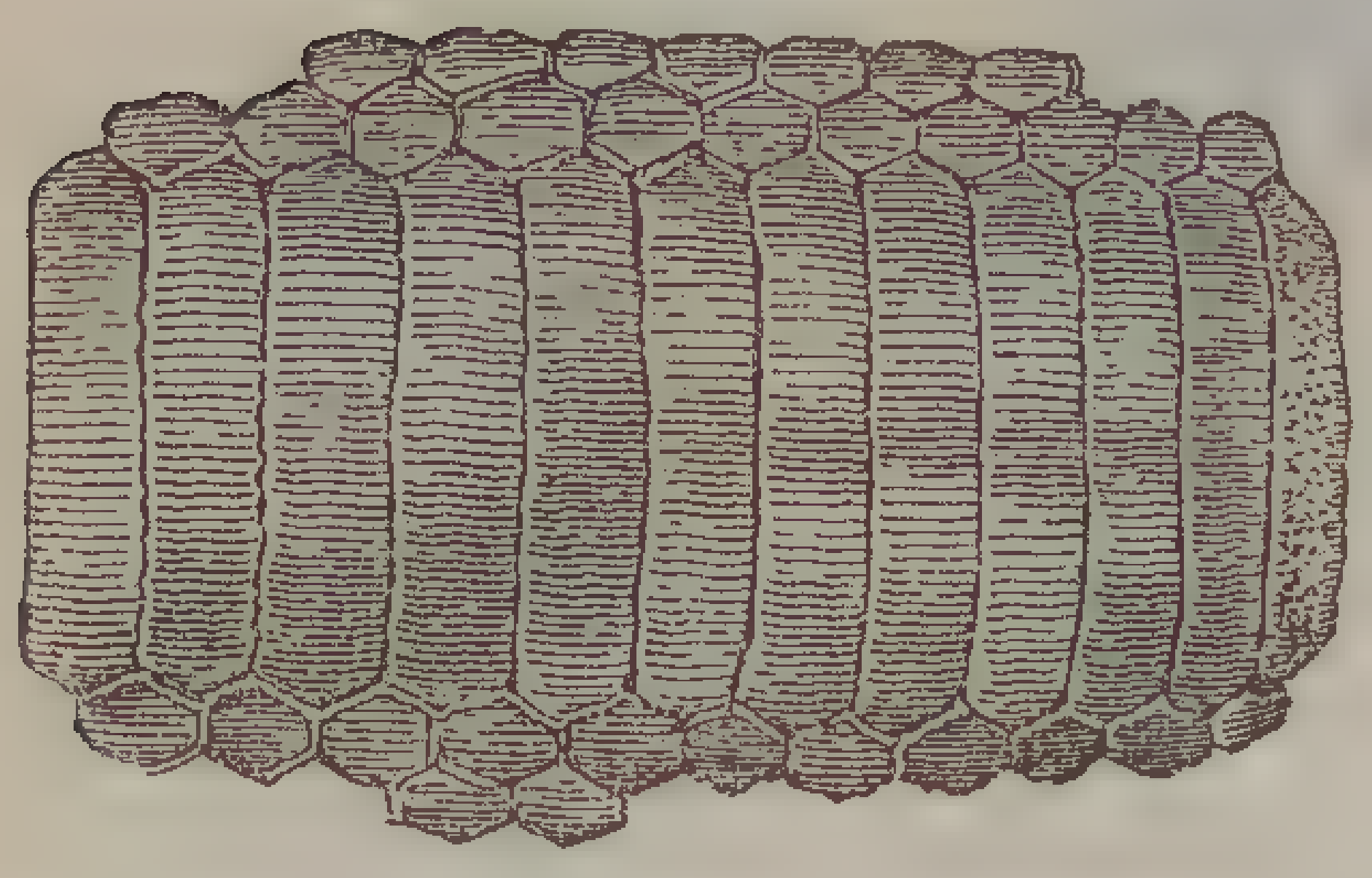
* Palæont. Soc. Monograph. Rept. pt. ii. p. 61.

when the climate was probably more genial; for amongst the companions of the sea-snake of Bracklesham was an extinct Gavial (*Gavialis Dixoni*, Owen), and numerous fish, such as now frequent the seas of warm latitudes, as the sword-fish (see fig. 208.), and gigantic rays of the genus *Myliobates* (see fig. 209.).

Fig. 208.

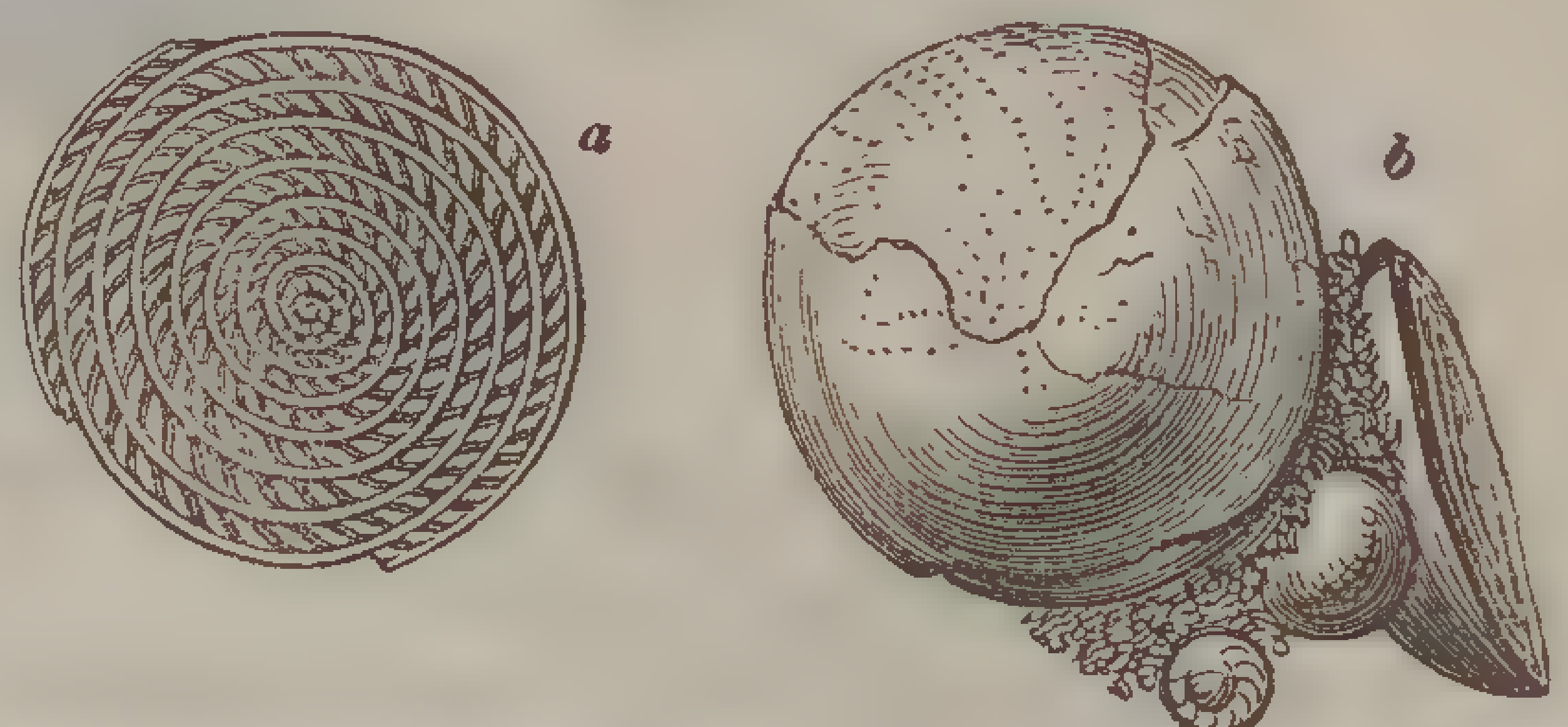
Prolonged premaxillary bone or "sword" of a fossil sword-fish (*Cœlorhynchus*). Bracklesham. Dixon's Fossils of Sussex, pl. 8.

Fig. 209.



Dental plates of *Myliobates Edwardsi.* Bracklesham Bay. Ibid. pl. 8.

Fig. 210.

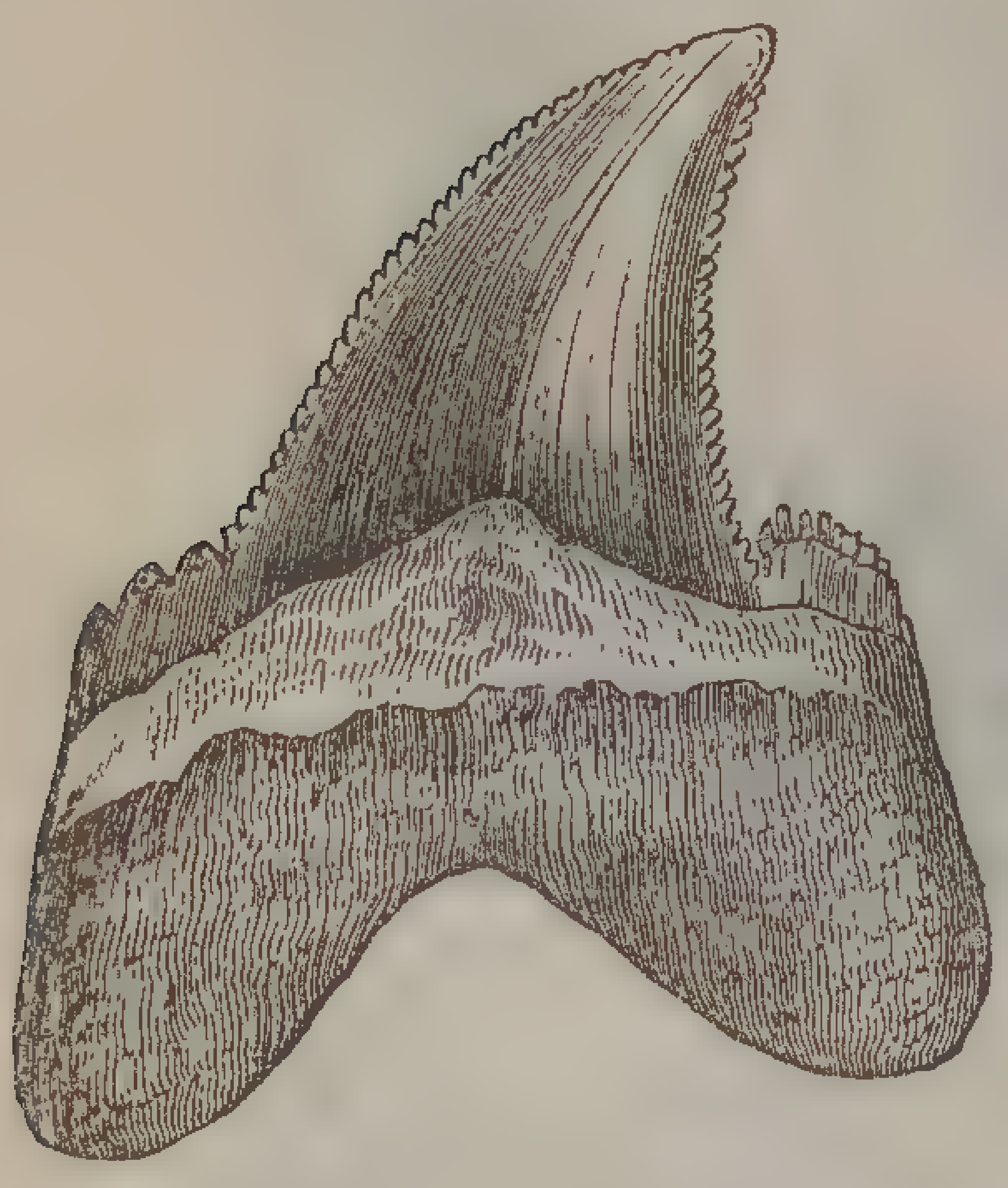


Nummulites (*Nummularia*) *lævigata.* Bracklesham. Ibid. pl. 8.

a. section of the nummulite.
b. group, with an individual showing the exterior of the shell.

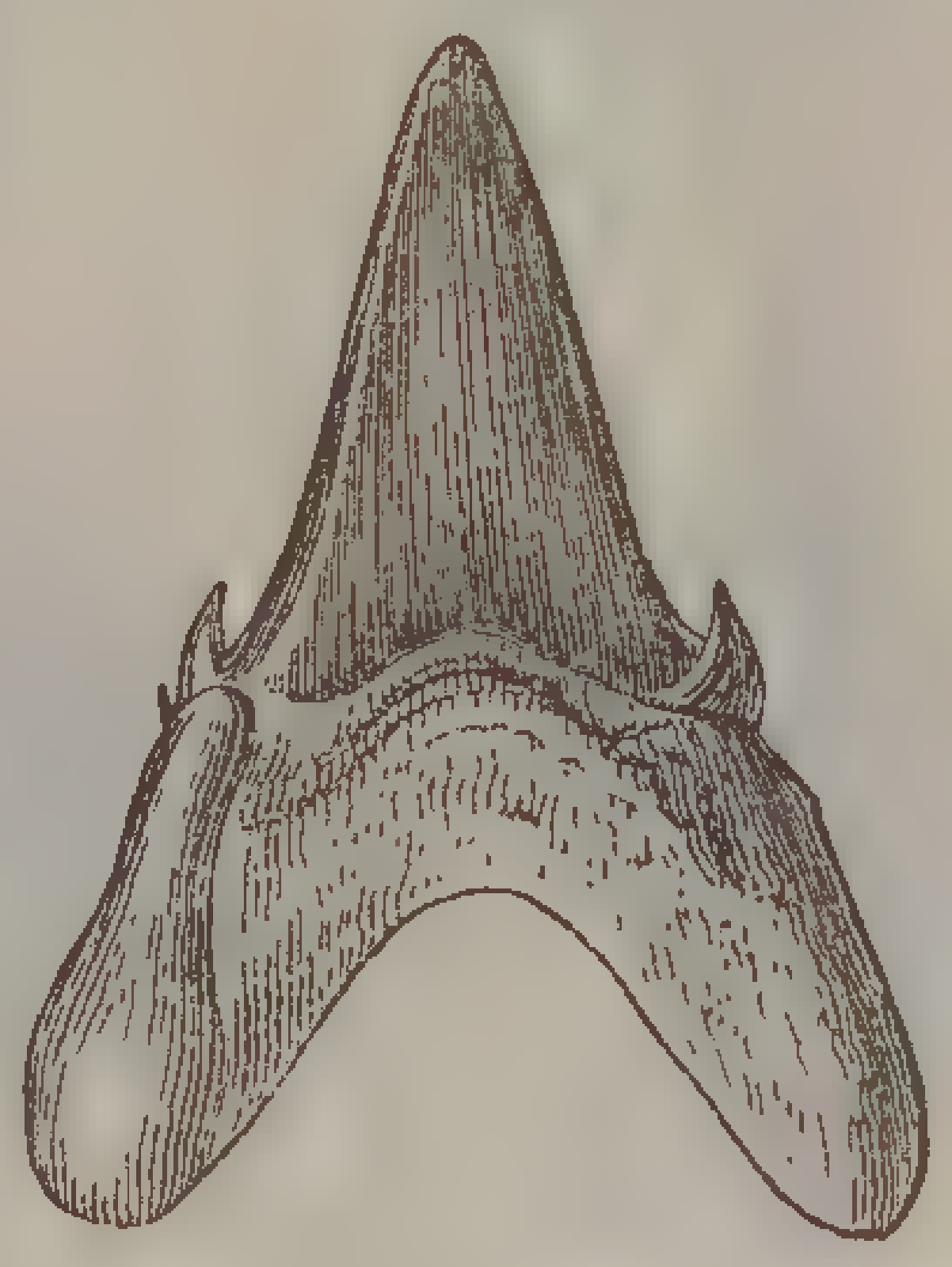
The teeth of sharks also, of the genera *Carcharodon*, *Otodus*, *Lamna*, *Galeocerdo*, and others, are abundant. (See figs. 211, 212, 213, 214.)

Fig. 211.



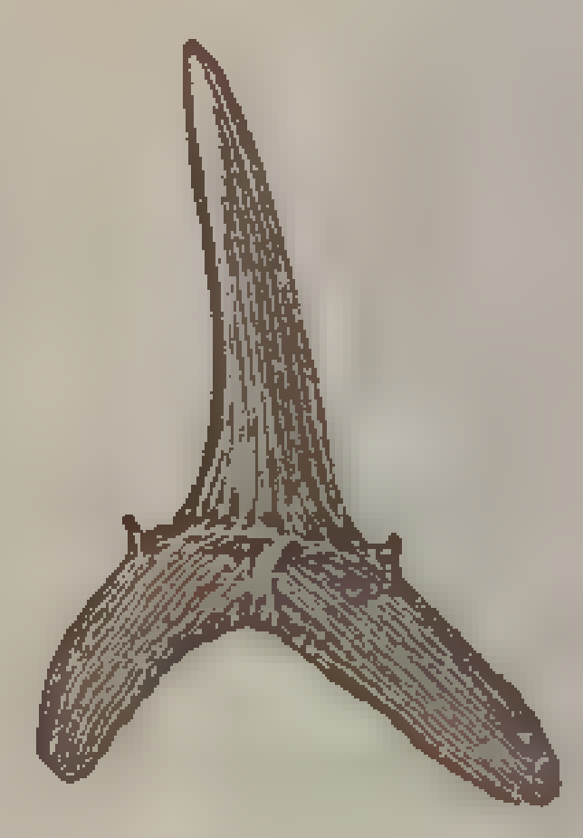
Carcharodon heterodon, Agass.

Fig. 212.



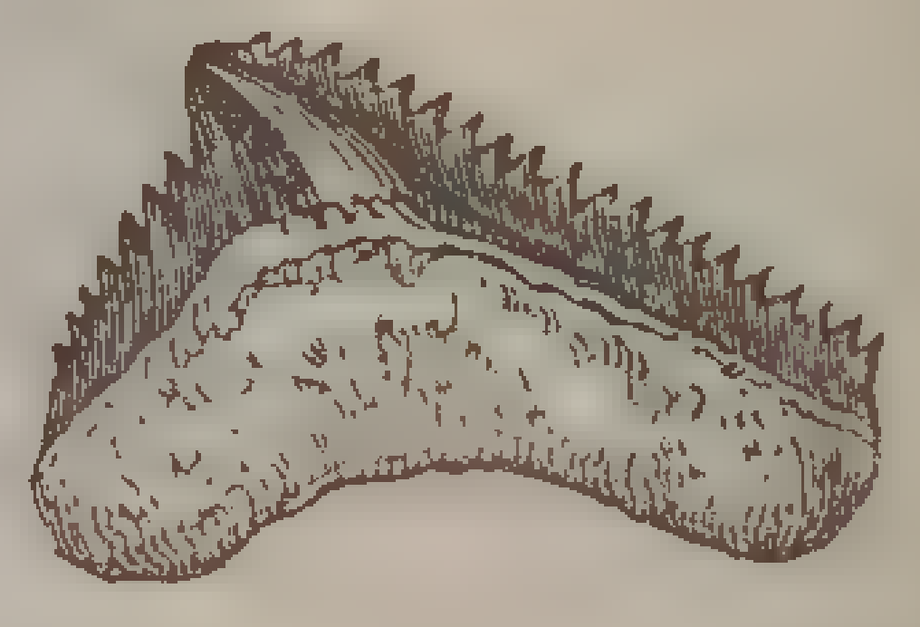
Otodus obliquus, Agass.

Fig. 213.



Lamna elegans, Agass.

Fig. 214.



Galeocerdo latidens, Agass.

Teeth of sharks from Bracklesham Bay.

The *Nummulites lævigata* (see fig. 210.), so characteristic of the lower beds of the calcaire grossier in France, where it sometimes forms stony layers, as near Compiegne, is very common at Bracklesham, together with *N. scabra* and *N. variolaria*. Out of 193 species of testacea procured from the Bagshot and Bracklesham beds in England, 126 occur in the calcaire grossier in France. It was clearly therefore coeval with that part of the Parisian series more nearly than with any other.

MARINE SHELLS OF BRACKLESHAM BEDS.

Fig. 215.

Pleurotoma attenuata, Sow.

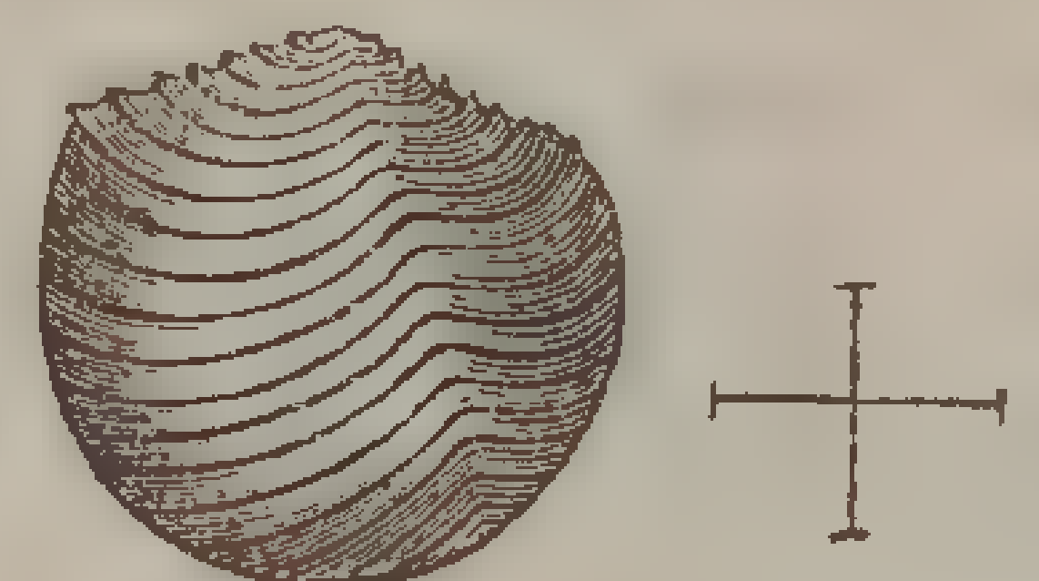
Fig. 216.

Voluta latrella, Lam.

Fig. 217.

Turritella, multisulcata, Lam.

Fig. 218.



Lucina serrata, Dixon. Magnified.

Fig. 219.

Conus deperditus.

LOWER EOCENE FORMATIONS OF ENGLAND.

London Clay proper (C. 1. Table, p. 209.).— This formation underlies the preceding, and consists of tenacious brown and bluish-gray clay, with layers of concretions called septaria, which abound chiefly in the brown clay, and are obtained in sufficient numbers from sea-cliffs near Harwich, and from shoals off the Essex coast, to be used for making Roman cement. The principal localities of fossils in the London clay are Highgate Hill, near London, the island of Sheppey, and Bognor in Hampshire. Out of 133 fossil shells, Mr. Prestwich found only 20 to be common to the calcaire grossier (from which 600 species have been obtained), while 33 are common to the "Lits Coquilliers" (p. 229.), in which only 200 species are known in France. We may presume, therefore, that the London clay proper is older than the calcaire grossier. This may perhaps remove a difficulty which M. Adolphe Brongniart has experienced when comparing the Eocene Flora of the neighbourhoods of London and Paris. The fossil species of the island of Sheppey, he observes, indicate a much more tropical climate than the Eocene Flora of France. Now the latter has been derived principally from the gypseous series, and resembles the vegetation of the borders of the Mediterranean rather than that of an equatorial region; whereas the older flora of Sheppey belongs to an antecedent epoch, separated from the period of the Paris gypsum by all the calcaire grossier and Bagshot series — in short, by the whole nummulitic formation properly so called.

Fig. 220.

Nipadites ellipticus, Bow. Fossil palm of Sheppey.

Mr. Bowerbank, in a valuable publication on the fossil fruits and seeds of the island of Sheppey, near London, has described no less than thirteen fruits of palms of the recent type *Nipa*, now only found in the Molucca and Philippine islands and in Bengal (see fig. 220.). In the delta of the Ganges, Dr. Hooker observed the large nuts of *Nipa fruticans* floating in such numbers in the various arms of that great river, as to obstruct the paddle-wheels of steam-boats. These plants are allied to the cocoa-nut tribe on the one side, and on the other to the *Pandanus*, or screw-pine. The fruits of other palms besides those of the cocoa-nut tribe are also met with in the clay of Sheppey; also three species of *Anona*, or custard apple; and cucurbitaceous fruits (of the gourd and melon family) are in considerable abundance. Fruits of various species of *Acacia* are in profusion, and these, although less decidedly tropical, imply a warm climate.

The contiguity of land may be inferred not only from these vegetable productions, but also from the teeth and bones of crocodiles and turtles, since these creatures, as Dr. Conybeare has remarked, must have resorted to some shore to lay their eggs. Of turtles there were numerous species referred to extinct genera. These are, for the most part, not equal in size to the largest living tropical turtles. A sea-snake, which must have been 13 feet long, of the genus *Palæophis* before mentioned (p. 215.), has also been described by Prof. Owen from Sheppey, of a different species from that of Bracklesham. A true crocodile, also, *Crocodilus, toliapicus*, and another saurian more nearly allied to the gavial, accompany the above fossils; also the relics of several birds and quadrupeds. One of these last belongs to the new genus *Hyracotherium* of Owen, allied to the Hyrax, Hog, and Chæropotamus; another is a *Lophiodon;* a third, a pachyderm called *Coryphodon eocænus* by Owen, larger than any existing tapir. All these animals seem to have inhabited the banks of the great river which floated down the Sheppey fruits. They imply the existence of a mammiferous fauna antecedent to the period when nummulites flourished in Europe and Asia, and therefore before the Alps, Pyrenees, and other mountain-chains now forming the backbones of great continents, were raised from the deep; nay, even before a part of the constituent rocky masses now entering into the central ridges of these chains had been deposited in the sea.

The marine shells of the London clay confirm the inference derivable from the plants and reptiles in favour of a high temperature. Thus many species of *Conus* and *Voluta* occur, a large *Cypræa, C. oviformis*, a very large *Rostellaria*, (fig. 223.), a species of *Cancellaria*, six species of *Nautilus* (fig. 225.), besides other cephalopoda of extinct genera, one of the most remarkable of which is the *Belosepia.** (fig. 226.) Among many characteristic bivalve shells are *Leda amygdaloides* (fig. 227.) and *Axinus angulatus* (fig. 228.), and among the Radiata a star-fish called *Astropecten* (fig. 229.).

These fossils are accompanied by a sword-fish (*Tetrapterus priscus*, Agassiz), about 8 feet long, and a saw-fish (*Pristis bisulcatus*, Ag.), about 10 feet in length; genera now foreign to the British seas. On the whole, no less than 50 species of fish have been described by M. Agassiz from these beds in Sheppey, and they indicate, in his opinion, a warm climate.

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* For description of Eocene Cephalopoda, see Monograph by F. E. Edwards, Palæontograph. Soc. 1849.

FOSSIL SHELLS OF THE LONDON CLAY.

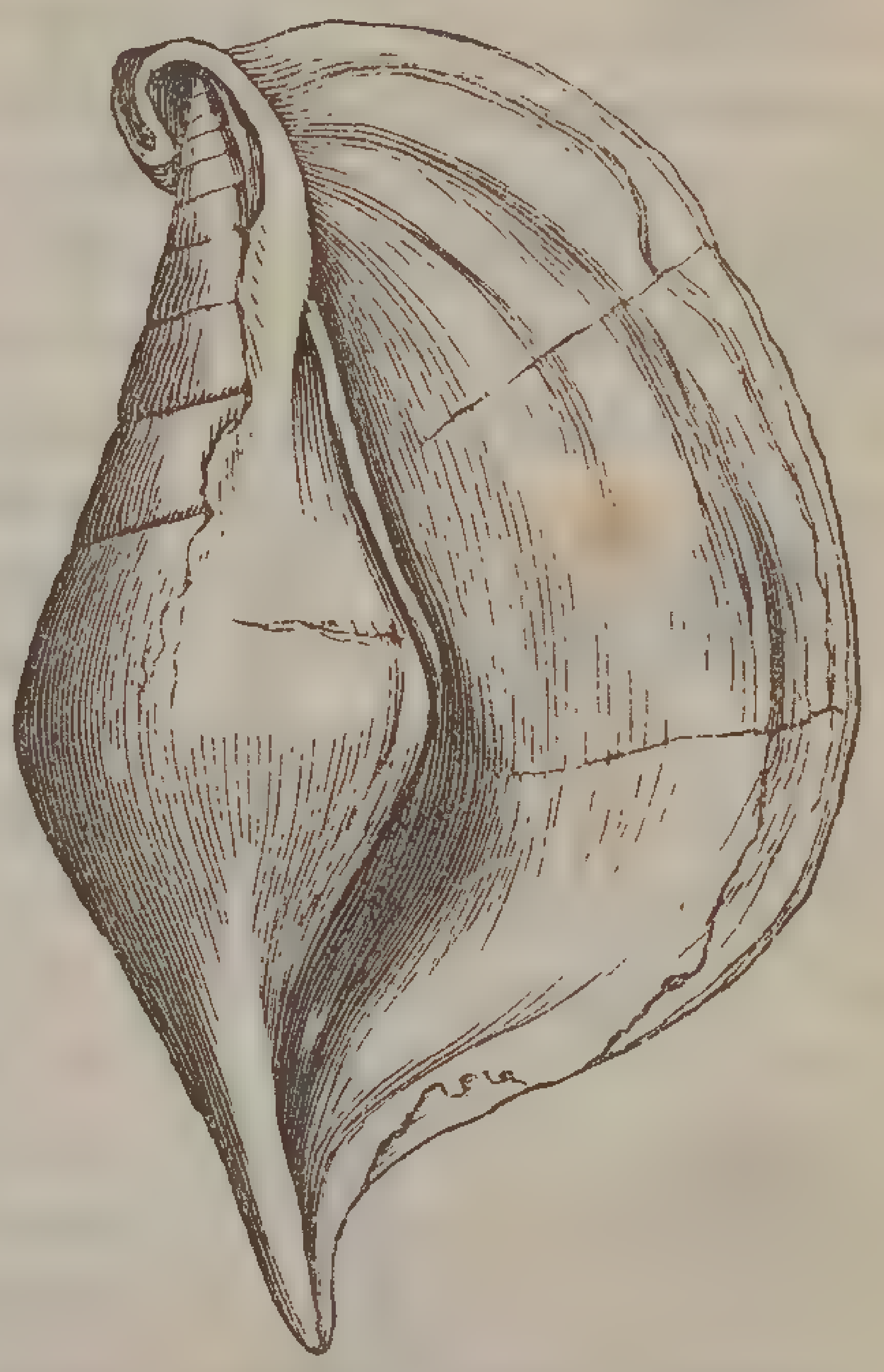
Fig. 221.

Voluta nodosa, Sow. Highgate.

Fig. 222.

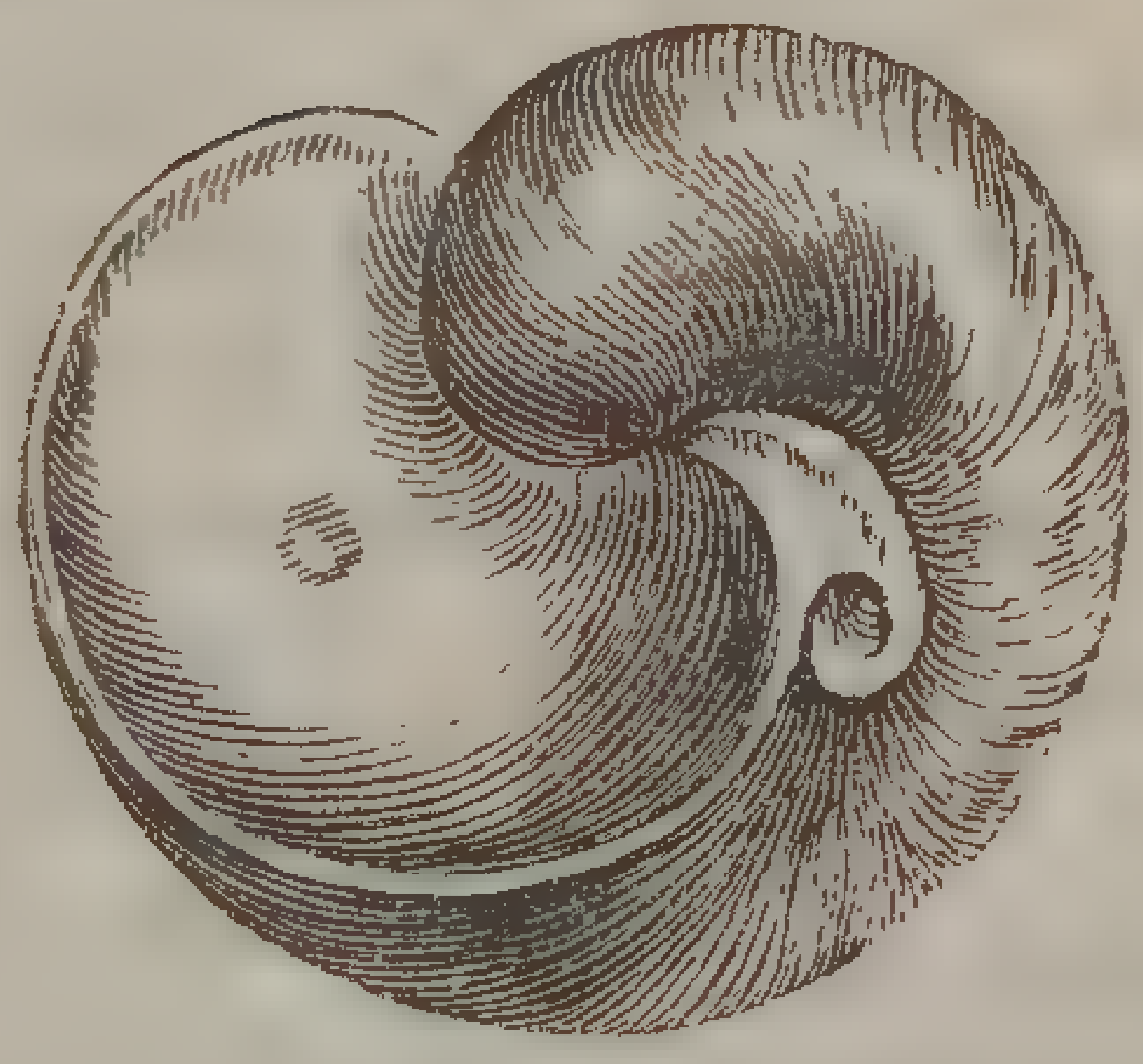
Phorus extensus, Sow. Highgate.

Fig. 223.



Rostellaria macroptera, Sow. One-third of nat. size; also found in the Barton clay.

Fig. 224.

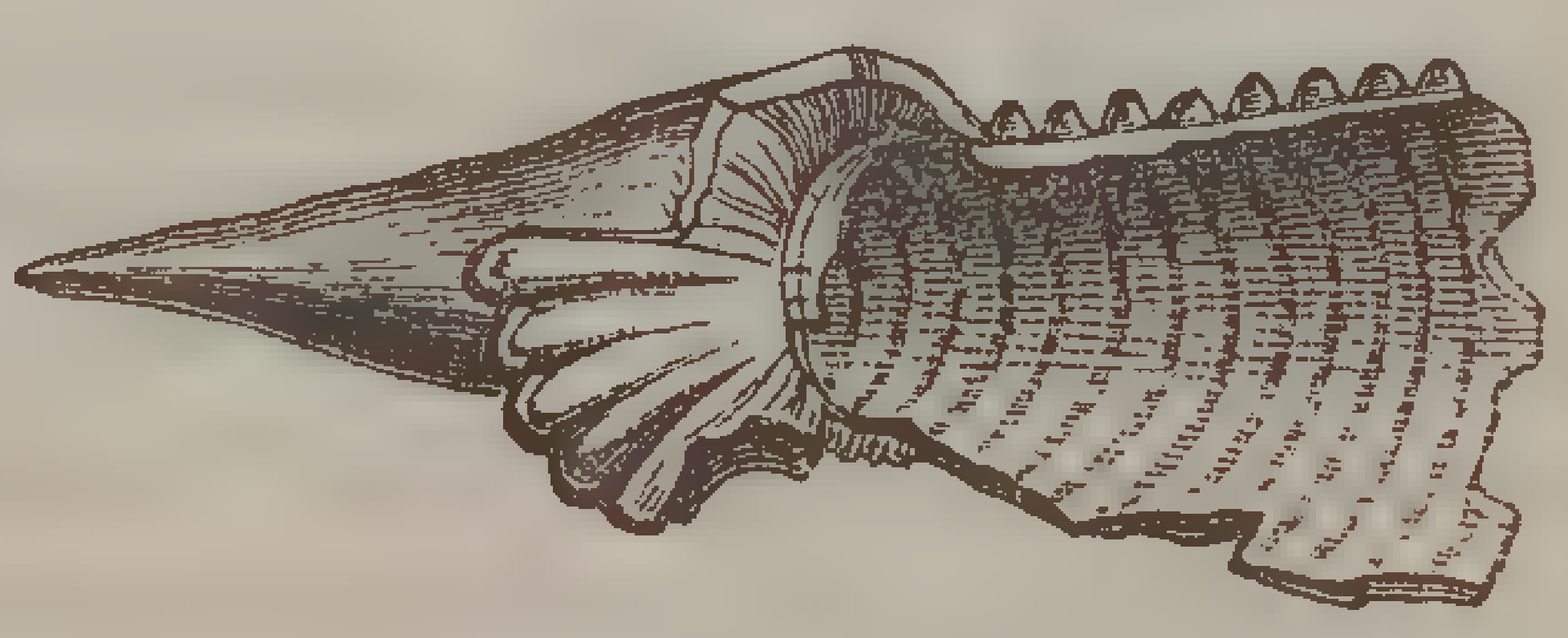


Nautilus centralis, Sow. Highgate.

Fig. 225.

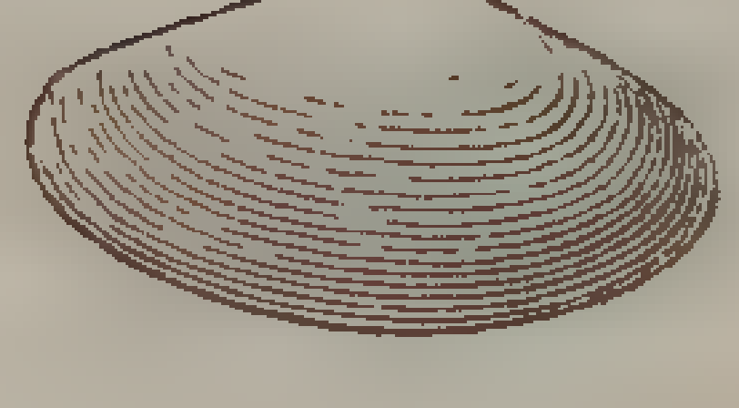
Aturia ziczac, Brown and Edwards. Syn. *Nautilus ziczac*, Sow. London clay. Sheppey.

Fig. 226.



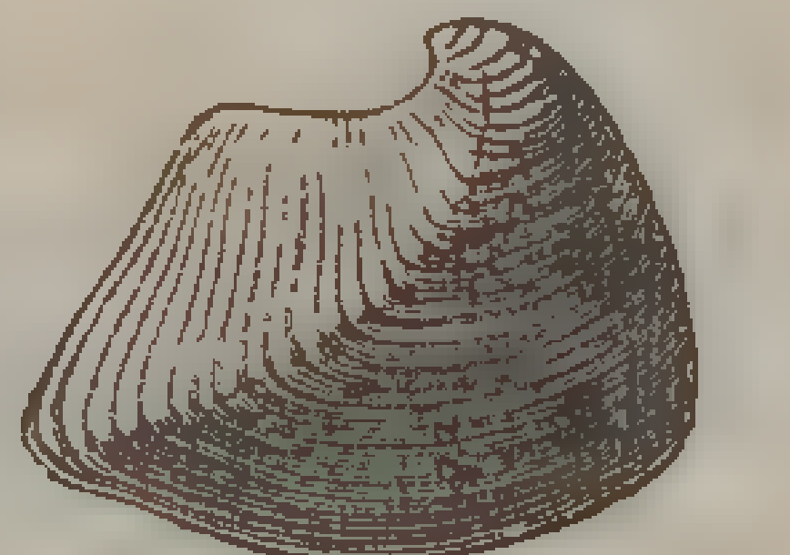
Belosepia sepioidea. De Blainv. London clay. Sheppey.

Fig. 227.



Leda amygdaloides. Highgate.

Fig. 228.



Axinus angulatus. London clay. Hornsea.

Fig. 229.

Astropecten crispatus, E. Forbes. Sheppey.

Strata of Kyson in Suffolk. — At Kyson, a few miles east of Woodbridge, a bed of Eocene clay, 12 feet thick, underlies the red crag. Beneath it is a deposit of yellow and white sand, of considerable interest, in consequence of many peculiar fossils contained in it. Its geological position is probably the lowest part of the

London clay proper. In this sand has been found the first example of a fossil quadrumanous animal discovered in Great Britain, namely, the teeth and part of a jaw, shown by Prof. Owen to belong to a monkey of the genus *Macacus* (see fig. 230.). The mammiferous fossils, first met with in the same bed, were those of an opossum (*Didelphys*) (see fig. 231.), and an insectivorous bat (fig. 232.), together with many teeth of fishes of the shark family. Mr. Colchester in 1840 obtained other mammalian relics from Kyson, among which Prof. Owen has recognized several teeth of the genus *Hyracotherium*, and the vertebræ of a large serpent, probably a *Palæophis*. As the remains both of the *Hyracotherium* and *Palæophis* were afterwards met with in the London clay, as before remarked, these fossils confirmed the opinion previously entertained, that the Kyson sand belongs to the Eocene period. The *Macacus*, therefore, constitutes the first example of any quadrumanous animal occurring in strata so old as the Eocene, or in a spot so far from the equator as lat. 52° N. It was not until after the year 1836 that the existence of any fossil quadrumana was brought to light. Since that period they have been discovered in France, India, and Brazil.

Fig. 230.

Molar of monkey (*Macacus*).

Fig. 231.

Molar tooth and part of jaw of opossum. From Kyson.*

Fig. 232.

Molars of insectivorous bats, twice nat. size. From Kyson, Suffolk.

Plastic or mottled clays and sands (C. 2. p. 209.).—The clays called plastic, which lie immediately below the London clay, received their name originally in France from being often used in pottery. Beds of the same age (the Woolwich and Reading series of Prestwich) are used for the like purposes in England.†

No formations can be more dissimilar on the whole in mineral character than the Eocene deposits of England and Paris; those of our own island being almost exclusively of mechanical origin,—accumulations of mud, sand, and pebbles; while in the neighbourhood of Paris we find a great succession of strata composed of limestones, some of them siliceous, and of crystalline gypsum and siliceous sandstone, and sometimes of pure flint used for millstones. Hence it is by no means an easy task to institute an exact comparison between the various members of the English and French series, and to settle their respective ages. It is clear that, on the sites both of Paris and London, a continual change was going on in the fauna and flora by the coming in of new species and the dying out of others; and contemporaneous changes of geographical conditions were also in progress in consequence of the rising and sinking of the land and bottom of the sea. A particular subdivision, therefore, of time was

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* Annals of Nat. Hist. vol. iv. No. 23. Nov. 1839.

† Prestwich, Waterbearing Strata of London, 1851.

occasionally represented in one area by land, in another by an estuary, in a third by the sea, and even where the conditions were in both areas of a marine character, there was often shallow water in one, and deep sea in another, producing a want of agreement in the state of animal life.

But in regard to that division of the Eocene series which we have now under consideration, we find an exception to the general rule, for, whether we study it in the basins of London, Hampshire, or Paris, we recognize everywhere the same mineral character. This uniformity of aspect must be seen in order to be fully appreciated, since the beds consist simply of sand, mottled clays, and well-rolled flint pebbles, derived from the chalk, and varying in size from that of a pea to an egg. These strata may be seen in the Isle of Wight in contact with the chalk, or in the London basin, at Reading, Blackheath, and Woolwich. In some of the lowest of them, banks of oysters are observed, consisting of *Ostrea bellovacina*, so common in France in the same relative position, and *Ostrea edulina*, scarcely distinguishable from the living eatable species. In the same beds at Bromley, Dr. Buckland found one large pebble to which five full-grown oysters were affixed, in such a manner as to show that they had commenced their first growth upon it, and remained attached to it through life.

In several places, as at Woolwich on the Thames, at Newhaven in Sussex, and elsewhere, a mixture of marine and freshwater testacea distinguishes this member of the series. Among the latter, *Melania inquinata* (see fig. 234.) and *Cyrena cuneiformis* (see fig. 233.) are very common, as in beds of corresponding age in France. They clearly indicate points where rivers entered the Eocene sea. Usually there is a mixture of brackish, freshwater, and marine shells, and

Fig. 233.

Cyrena cuneiformis, Min. Con.
Natural size.

Fig. 234.

Melania inquinata, Des. Nat. size.
Syn. *Cerithium melanoides*, Min. Con.

sometimes, as at Woolwich, proofs of the river and the sea having successively prevailed on the same spot. At New Charlton, in the suburbs of Woolwich, Mr. De la Condamine discovered in 1849, and pointed out to me, a layer of sand associated with well-rounded flint pebbles in which numerous individuals of the *Cyrena tellinella* were seen standing endwise with both their valves united, the posterior extremity of each shell being uppermost, as would happen if the mollusks had died in their natural position. I have described* a bank of sandy mud, in the delta of the Alabama river at Mobile, on the borders of the Gulf of Mexico, where in 1846 I dug out at low tide specimens of living species of *Cyrena* and of a *Gnathodon*, which were similarly placed with their shells erect, or in a position which enables the animal to protrude its siphon upwards, and draw in or reject water at pleasure. The water at Mobile is usually fresh, but sometimes brackish. At Woolwich a body of river-water must have flowed permanently into the sea where the *Cyrenæ* lived, and they may have been killed suddenly by an influx of pure salt water, which invaded the spot when the river was low, or when a subsidence of land took place. Traced in one direction, or eastward towards Herne Bay, the Woolwich beds assume more and more of a marine character; while in an opposite, or south-western direction, they become, as near Chelsea and other places, more freshwater, and contain *Unio*, *Paludina*, and layers of lignite, so that the land drained by the ancient river seems clearly to have been to the south-west of the present site of the metropolis.

Before the minds of geologists had become familiar with the theory of the gradual sinking of land, and its conversion into sea at different periods, and the consequent change from shallow to deep water, the freshwater and littoral character of this inferior group appeared strange and anomalous. After passing through hundreds of feet of London clay, proved by its fossils to have been deposited in deep salt water, we arrive at beds of fluviatile origin, and in the same underlying formation masses of shingle, attaining at Blackheath, near London, a thickness of 50 feet, indicate the proximity of land, where the flints of the chalk were rolled into sand and pebbles, and spread continuously over wide spaces. Such shingle always appears at the bottom of the series, whether in the Isle of Wight, or in the Hampshire or London basins. It may be asked why they did not constitute simply narrow littoral zones, such as we might look for on an ancient sea-shore. In reply, Mr. Prestwich has suggested that such zones of shingle may have been slowly formed on a large scale at the period of the Thanet sands (C. 3. p. 209.), and while the land was sinking the well-rolled pebbles may have been dispersed simultaneously over considerable areas, and exposed during gradual submergence to the action of the waves of the sea, aided occasionally by tidal currents and river floods.

Thanet sands (C. 3. p. 209.).—The mottled or plastic clay of the

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* Second Visit to the United States, vol. ii. p. 104.

Isle of Wight and Hampshire is often seen in actual contact with the chalk, constituting in such places the lowest member of the British Eocene series. But in other points another formation of marine origin, characterized by a somewhat different assemblage of organic remains, has been shown by Mr. Prestwich to intervene between the chalk and the Woolwich series. For these beds he has proposed the name of "Thanet Sands," because they are well seen in the Isle of Thanet, in the northern part of Kent, and on the sea-coast between Herne Bay and the Reculvers, where they consist of sands with a few concretionary masses of sandstone, and contain among other fossils *Pholadomya cuneata, Cyprina Morrisii, Corbula longirostris, Scalaria Bowerbankii,* &c. The greatest thickness of these beds is about 90 feet.

FRENCH MIDDLE EOCENE FORMATIONS.

GENERAL TABLE OF FRENCH EOCENE STRATA.

A. UPPER EOCENE (*Lower Miocene of many French authors*).

	English Equivalents.
A. Calcaire de la Beauce, or upper freshwater, see p. 185., and Grès de Fontainebleau, &c.	Hempstead series, see p. 193.

B. MIDDLE EOCENE.

B. 1. Gypseous series and Middle freshwater calcaire lacustre moyen.	Bembridge series, p. 195.
B. 2. Calcaire siliceux, (in part contemporaneous with the succeeding group ?)	Lower part of the Bembridge series.
B. 3. Grès de Beauchamp, or Sables Moyens.	Osborne series, and upper and middle part of Headon series, Isle of Wight.
B. 4. Upper Calcaire Grossier (Cailasse) and Middle Calcaire Grossier.	Headon Hill Sands, Barton, Upper Bagshot and part of Bracklesham beds.
B. 5. Lower Calcaire Grossier or Glauconie Grossière.	Bracklesham beds.
B. 6. Soissonnais Sans or Lits coquilliers.	Lower Bagshot. Intermediate in age between the Bracklesham beds and London Clay

C. LOWER EOCENE.

C. Argile plastique et lignite.	Plastic clay and sand, with lignite (Woolwich and Reading series).

The tertiary formations in the neighbourhood of Paris consist of a series of marine and freshwater strata, alternating with each other, and filling up a depression in the chalk. The area which they occupy has been called the Paris basin, and is about 180 miles in its greatest length, from north to south, and about 90 miles in breadth from east to west (see Map, p. 196.). MM. Cuvier and Brongniart attempted, in 1810, to distinguish five different groups, comprising three freshwater and two marine, which were supposed to imply that the waters of the ocean, and of rivers and lakes, had been by turns admitted into and excluded from the same area. Investigations since made in the Hampshire and London basins have rather tended to confirm these views, at least so far as to show, that since the commencement of the Eocene period there have been great movements of the bed of the sea, and of the adjoining lands, and that the superposition of deep sea to shallow water deposits (the London clay, for example, to the Woolwich beds) can only be explained by referring to such movements. Nevertheless, it appears, from the researches of M. Constant Prevost, that some of the alternations and intermixtures of freshwater and marine deposits, in the Paris basin, may be accounted for by imagining both to have been simultaneously in progress, in the same bay of the same sea, or a gulf into which many rivers entered.

To enlarge on the numerous subdivisions of the Parisian strata, would lead me beyond my present limits; I shall therefore give some examples only of the most important formations enumerated in the foregoing Table, p. 223.

Beneath the Upper Eocene or "Upper marine sands," A, already spoken of, (p. 195.), we find, in the neighbourhood of Paris, a series of white and green marls, with subordinate beds of gypsum, B. These are most largely developed in the central parts of the Paris basin, and, among other places, in the Hill of Montmartre, where its fossils were first studied by M. Cuvier.

The gypsum quarried there for the manufacture of plaster of Paris occurs as a granular crystalline rock, and, together with the associated marls, contains land and fluviatile shells, together with the bones and skeletons of birds and quadrupeds. Several land plants are also met with, among which are fine specimens of the fan palm or palmetto tribe (*Flabellaria*). The remains also of freshwater fish, and of crocodiles and other reptiles, occur in the gypsum. The skeletons of mammalia are usually isolated, often entire, the most delicate extremities being preserved; as if the carcases, clothed with their flesh and skin, had been floated down soon after death, and while they were still swollen by the gases generated by their first decomposition. The few accompanying shells are of those light kinds which frequently float on the surface of rivers, together with wood.

M. Prevost has therefore suggested that a river may have swept away the bodies of animals, and the plants which lived on its borders, or in the lakes which it traversed, and may have carried them down into the centre of the gulf into which flowed the waters impregnated with sulphate of lime. We know that the Fiume Salso in Sicily enters the sea so charged with various salts that the thirsty cattle refuse to drink of it. A stream of sulphureous water, as white as milk, descends into the sea from the volcanic mountain of Idienne, on the east of Java; and a great body of hot water, charged with sulphuric acid, rushed down from the same volcano on one occasion, and inundated a large tract of country, destroying, by its noxious properties, all the vegetation.* In like manner the Pusanibio, or "Vinegar River," of Colombia, which rises at the foot of Puracé, an extinct volcano, 7,500 feet above the level of the sea, is strongly impregnated with sulphuric and hydrochloric acids and with oxide of iron. We may easily suppose the waters of such streams to have properties noxious to marine animals, and in this manner the entire absence of marine remains in the ossiferous gypsum may be explained.† There are no pebbles or coarse sand in the gypsum; a circumstance which agrees well with the hypothesis that these beds were precipitated from water holding sulphate of lime in solution, and floating the remains of different animals.

In this formation the relics of about fifty species of quadrupeds, including the genera *Paleotherium* (see fig. 191.), *Anoplotherium* (see fig. 190.), and others, have been found, all extinct, and nearly four-fifths of them belonging to a division of the order *Pachydermata*, which is now represented by only four living species; namely, three tapirs and the daman of the Cape. With them a few carnivorous animals are associated, among which are the *Hyænodon dasyuroides*, and a species of dog, *Canis Parisiensis*, and a weasel, *Cynodon Parisiensis*. Of the *Rodentia*, are found a squirrel; of the *Insectivora*, a bat; while the *Marsupialia* (an order now confined to America, Australia, and some contiguous islands) are represented by an opossum.

Of birds, about ten species have been ascertained, the skeletons of some of which are entire. None of them are referable to existing species.‡ The same remark applies to the fish, according to MM. Cuvier and Agassiz, as also to the reptiles. Among the last are crocodiles and tortoises of the genera *Emys* and *Trionyx*.

The tribe of land quadrupeds most abundant in this formation is such as now inhabits alluvial plains and marshes, and the banks of rivers and lakes, a class most exposed to suffer by river inundations. Among these were several species of *Paleothere*, a genus before alluded to (p. 211.). These were associated with the *Anoplotherium*, a tribe intermediate between pachyderms and ruminants. One of the three divisions of this family was called by Cuvier *Xiphodon* (see fig. 235.). Their forms were slender and elegant, and one, named *Xiphodon gracile* (fig. 235.), was about the size of the chamois; and Cuvier inferred from the skeleton that it was as light, graceful, and agile as the gazelle.

When the French osteologist declared, in the early part of the present century, that all the fossil quadrupeds of the gypsum of Paris were extinct, the announcement of so startling a fact, on such high authority, created a powerful sensation, and from that time a new impulse was given throughout Europe to the progress of geological investigation. Eminent naturalists, it is true, had long

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* Leyde Magaz. voor Wetensch Konst en Lett., partie v. cahier i. p. 71. Cited by Rozet, Journ. de Géologie, tom. i. p. 43.

† M. C. Prevost, Submersions Itératives, &c. Note 23.

‡ Cuvier, Oss. Foss., tom. iii. p. 255.

before maintained that the shells and zoophytes, met with in many ancient European rocks, had ceased to be inhabitants of the earth, but the majority even of the educated classes continued to believe that the species of animals and plants now contemporary with man, were the same as those which had been called into being when the planet itself was created. It was easy to throw discredit upon the new doctrine by asking whether corals, shells, and other creatures previously unknown, were not annually discovered? and whether living forms corresponding with the fossils might not yet be dredged up from seas hitherto unexamined? But from the era of the publication of Cuvier's Ossements Fossiles, and still more his popular Treatise called "A Theory of the Earth," sounder views began to prevail. It was clearly demonstrated that most of the mammalia found in the gypsum of Montmartre differed even generically from any now known to exist, and the extreme improbability that any of them, especially the larger ones, would ever be found surviving in continents yet unexplored, was made manifest. Moreover, the non-admixture of a single living species in the midst of so rich a fossil fauna was a striking proof that there had existed a state of the earth's surface zoologically unconnected with the present state of things.

Fig. 235.

Xiphodon gracile, or *Anoplotherium gracile*, Cuvier. Restored outline.

Calcaire siliceux, or Travertin inférieur, B. 2. — This compact siliceous limestone extends over a wide area. It resembles a precipitate from the waters of mineral springs, and is often traversed by small empty sinuous cavities. It is, for the most part, devoid of organic remains, but in some places contains freshwater and land species, and never any marine fossils. The siliceous limestone and the calcaire grossier usually occupy distinct parts of the Paris basin, the one attaining its fullest development in those places where the other is of slight thickness. They are described by some writers as alternating with each other towards the centre of the basin, as at Sergy and Osny; and M. Prevost concludes, that while to the north, where the bay was probably open to the sea, a marine limestone was formed, another deposit of freshwater origin was introduced to the southward, or at the head of the bay. It is supposed that during the Eocene period, as now, the ocean was to the north, and the continent, where the great lakes existed, to the south. From that southern region we may suppose a body of freshwater to have descended, charged with carbonate of lime and silica, the water being perhaps in sufficient volume to freshen the upper end of the bay.

The gypsum, with its associated marl and limestone, is, as before stated, in greatest force towards the centre of the basin, where the calcaire grossier and calcaire siliceux are less fully developed. Hence M. Prevost infers, that while those two principal deposits were gradually in progress, the one towards the north, and the other towards the south, a river descending from the east may have brought down the gypseous and marly sediment.

Grès de Beauchamp or Sables moyens, B. 3. — In some parts of the Paris basin, sands and marls, called the Grès de Beauchamp, or Sables moyens, divide the gypseous beds from the calcaire grossier proper. These sands, in which a small nummulite (*N. variolaria*) is very abundant, contain more than 300 species of marine shells, many of them peculiar, but others common to the next division.

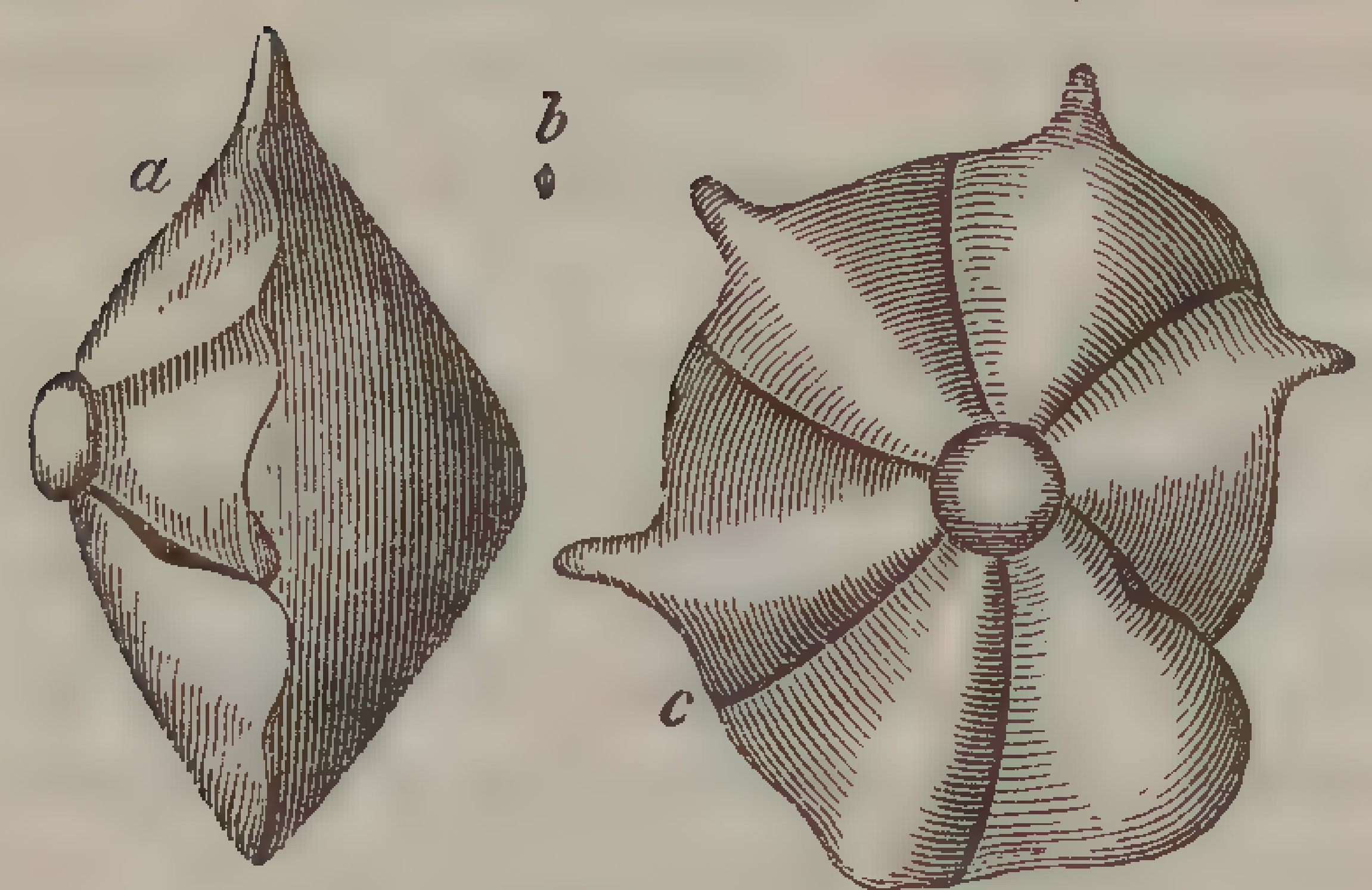
Calcaire grossier, upper and middle, B. 4. — The upper division of this group consists in great part of beds of compact, fragile limestone, with some intercalated green marls. The shells in some parts are a mixture of *Cerithium*, *Cyclostoma*, and *Corbula;* in others *Limneus*, *Cerithium*, *Paludina*, &c. In the latter, the bones of reptiles and mammalia, *Paleotherium* and *Lophiodon*, have been found. The middle division, or calcaire grossier proper, consists of a coarse limestone, often passing into sand. It contains the greater number of the fossil shells which characterize the Paris basin. No less than 400 distinct species have been procured from a single spot near Grignon, where they are embedded in a calcareous sand, chiefly formed of comminuted shells, in which, nevertheless, individuals in a perfect state of preservation, both of marine, terrestrial, and freshwater species, are mingled together. Some of the marine shells may have lived on the spot; but the *Cyclostoma* and *Limneus* must have been brought thither by rivers and currents, and the quantity of triturated shells implies considerable movement in the waters.

Nothing is more striking in this assemblage of fossil testacea than the great proportion of species referable to the genus *Cerithium* (see p. 30. fig. 44.). There occur no less than 137 species of this genus in the Paris basin, and almost all of them in the calcaire grossier. Most of the living *Cyrithia* inhabit the sea near the mouths of rivers, where the waters are brackish; so that their abundance in the marine strata now under consideration is in harmony with the hypothesis, that the Paris basin formed a gulf into which several rivers flowed, the sediment of some of which gave rise to the beds of clay and lignite before mentioned; while a distinct freshwater limestone, called calcaire siliceux, already described, was precipitated from the waters of others situated farther to the south.

In some parts of the calcaire grossier round Paris, certain beds occur of a stone used in building, and called by the French geologists "Miliolite limestone." It is almost entirely made up of millions of microscopic shells, of the size of minute grains of sand, which all belong to the class Foraminifera. Figures of some of these are given in the annexed woodcut. As this miliolitic stone never occurs in the Faluns, or Miocene strata of Brittany and Touraine, it often furnishes the geologist with a useful criterion for distinguishing the detached Eocene and Miocene formations, scattered over those and other adjoining provinces. The discovery of the remains of Paleotherium and other mammalia in some of the upper beds of the calcaire grossier shows that these land animals began to exist before the deposition of the overlying gypseous series had commenced.

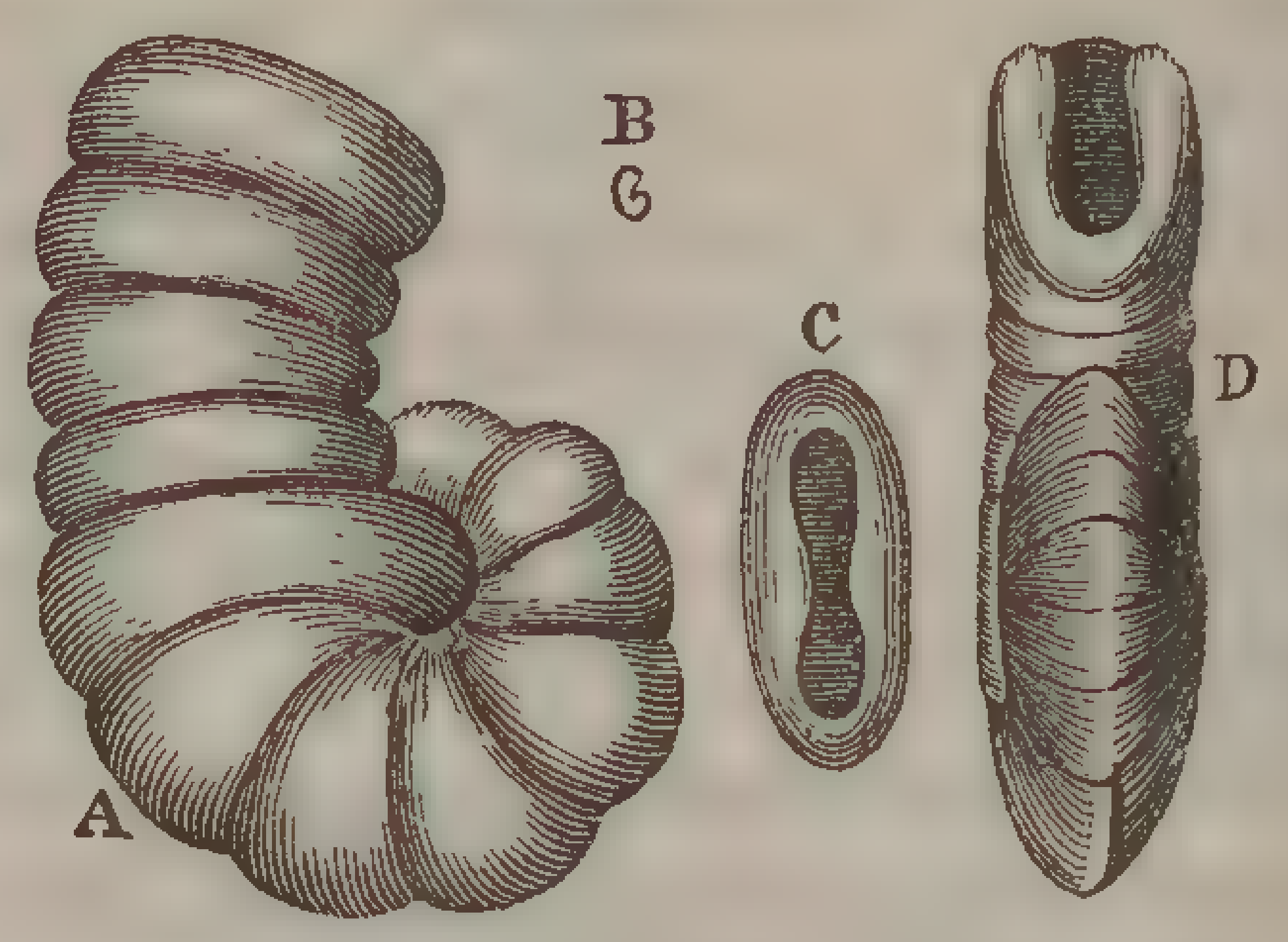
EOCENE FORAMINIFERA.

Fig. 236.



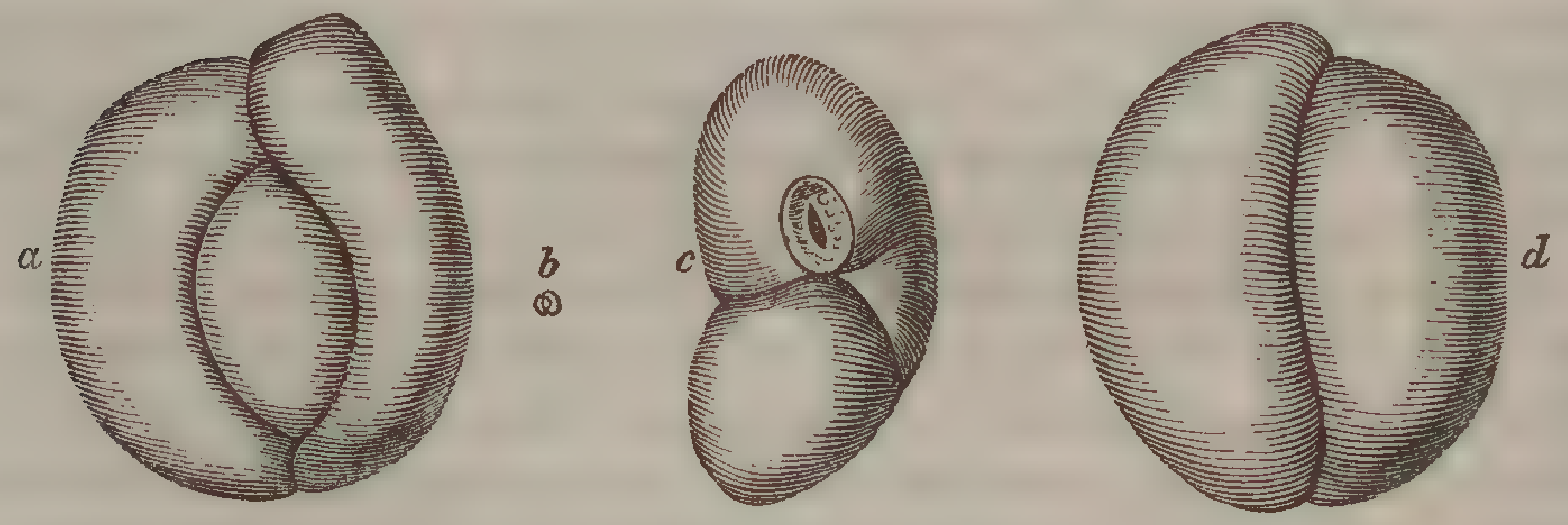
Calcarina rarispina, Desh.
b. natural size. *a*, *c*. same magnified.

Fig. 237.



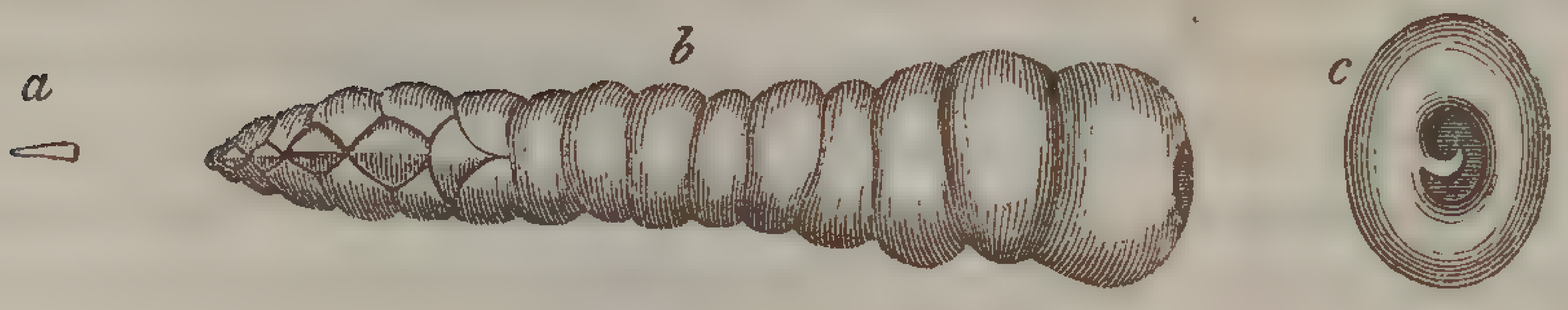
Spirolina stenostoma, Desh.
B. natural size. A, C, D. same magnified.

Fig. 238.



Triloculina inflata, Desh.
b. natural size. *a*, *c*, *d*. same magnified.

Fig. 239.

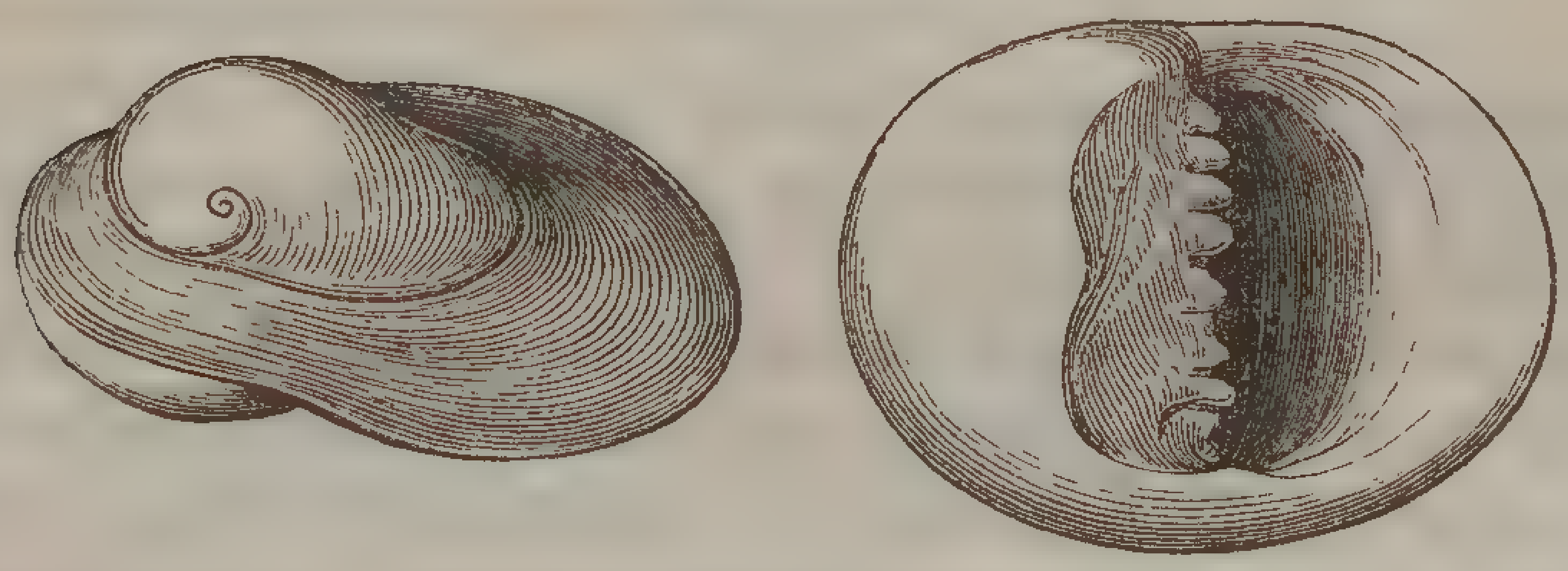


Clavulina corrugata, Desh.
a. natural size. *b*, *c*. same magnified.

Lower Calcaire grossier, or Glauconie grossière, B. 5. — The lower part of the calcaire grossier, which often contains much green earth, is characterized at Auvers, near Pontoise, to the north of Paris, and still more in the environs of Compiegne, by the abundance of nummulites, consisting chiefly of *N. lævigata*, *N. scabra*, and *N. Lamarcki*, which constitute a large proportion of some of the stony strata, though these same foraminifera are wanting in beds of similar age in the immediate environs of Paris.

Soissonnais Sands or Lits coquilliers, B. 6. — Below the preceding formation, shelly sands are seen, of considerable thickness, especially at Cuisse-Lamotte, near Compiegne, and other localities in the Soissonnais, about fifty miles N.E. of Paris, from which about 300 species of shells have been obtained, many of them common to the Calcaire grossier and the Bracklesham beds of England, and many peculiar. The *Nummulites planulata* is very abundant, and the most characteristic shell is the *Nerita conoidea*, Lam., a fossil which has a very wide geographical range; for, as M. D'Archiac remarks, it accompanies the nummulitic formation from Europe to India, having been found in Cutch, near the mouths of the Indus, associated with *Nummulites scabra*. No less than thirty-three shells of this group are said to be identical with shells of the London clay proper, yet, after visiting Cuisse-Lamotte and other localities of the "Sables inférieures" of Archiac, I agree with Mr. Prestwich, that the latter are probably newer than the London clay, and perhaps older than the Bracklesham beds of England. The London clay seems to be unrepresented in France, unless partially so, by these sands.* One of the shells of the sandy beds of the Soissonnais is adduced by M. Deshayes as an example of the changes which certain species

Fig. 240.



Nerita conoidea, Lam.
Syn. *N. Schemidelliana*, Chemnitz.

Fig. 241.

Cardium porulosum. Paris and London basins.

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* D'Archiac, Bulletin, tom. x.; and Prestwich, Geol. Quart. Journ. 1847, p. 377.

underwent in the successive stages of their existence. It seems that different varieties of the *Cardium porulosum* are characteristic of different formations. In the Sossonnais this shell acquires but a small volume, and has many peculiarities, which disappear in the lowest beds of the calcaire grossier. In these the shell attains its full size, with many distinctive characters, which are again modified in the uppermost beds of the calcaire grossier; and these last modifications of form are preserved throughout the "upper marine" (or Upper Eocene) series.*

Argile plastique (C. Table, p. 223.).—At the base of the tertiary system in France are extensive deposits of sands, with occasional beds of clay used for pottery, and called "argile plastique." Fossil oysters (*Ostrea bellovacina*) abound in some places, and in others there is a mixture of fluviatile shells, such as *Cyrena cuneiformis* (fig. 233. p. 321.), *Melania inquinata* (fig. 234.), and others, frequently met with in beds occupying the same position in the valley of the Thames. Layers of lignite also accompany the inferior clays and sands.

Immediately upon the chalk at the bottom of all the tertiary strata in France there generally is a conglomerate or breccia of rolled and angular chalk-flints, cemented by siliceous sand. These beds appear to be of littoral origin, and imply the previous emergence of the chalk, and its waste by denudation.

Whether the Thanet sands before mentioned (p. 222.) are exactly represented in the Paris basin is still a matter of discussion.

Wide extent of the nummulitic formation in Europe, Asia, &c.—When I visited Belgium and French Flanders in 1851, with a view of comparing the tertiary strata of those countries with the English series, I found that all the beds between the Upper Eocene or Limburg formations, and the Lower Eocene or London clay proper, might be conveniently divided into three sections, distinguished, among other paleontological characters, by three different species of nummulites, *N. variolaria* in the upper beds, *N. lævigata* in the middle, and *N. planulata* in the lower. After I had adopted this classification, I found, what I had overlooked or forgotten, that the superposition of these three species in the order here assigned to them, had been previously recognized in the North of France, in 1842, by Viscount D'Archiac. The same author, in the valuable monograph recently published by him†, has observed, that a somewhat similar distribution of these and other species in time, prevails very widely in the South of France and in the Pyrenees, as well as in the Alps and Apennines, and in Istria,—the lowest nummulitic beds being characterized by fewer and smaller species, the middle by a greater number and by those which individually attain the largest dimensions, and the uppermost beds again by small species.

In the treatise alluded to, M. D'Archiac describes no less than fifty-two species of this genus, and considers that they are all of them cha-

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* Coquilles caractéristiques des terrains, 1831.

† Animaux foss. du groupe nummul. de l'Inde: Paris, 1853.

racteristic of those tertiary strata which I have called Middle Eocene. In very few instances at least do certain species diverge from this narrow limit, whether into incumbent or subjacent tertiary formations, it being rather doubtful whether more than one of them, *Nummulites intermedia*, also a Middle Eocene fossil, ascends so high as the Miocene formation, or whether any of them descend to the level of the London clay. Certainly they have never been traced so low down as the marine beds, coeval with the Plastic clay or Lignite, in any country of which the geology has been well worked out. This conclusion is a very unexpected result of recent inquiry, since for many years it was a matter of controversy whether the nummulitic rocks of the Alps and Pyrenees ought not to be regarded as cretaceous rather than Eocene. The late M. Alex. Brongniart first declared the specific identity of many shells of the marine strata near Paris, and those of the nummulitic formation of Switzerland, although he obtained these last from the summit of the Diablerets, one of the loftiest of the Swiss Alps, which rises more than 10,000 feet above the level of the sea.

The nummulitic limestone of the Alps is often of great thickness, and is immediately covered by another series of strata of dark-coloured slates, marls, and fucoidal sandstones, to the whole of which the provincial name of "flysch" has been given in parts of Switzerland. The researches of Sir Roderick Murchison in the Alps in 1847 have shown that all these tertiary strata enter into the disturbed and loftiest portions of the Alpine chain, to the upheaval of which they enable us therefore to assign a comparatively modern date.

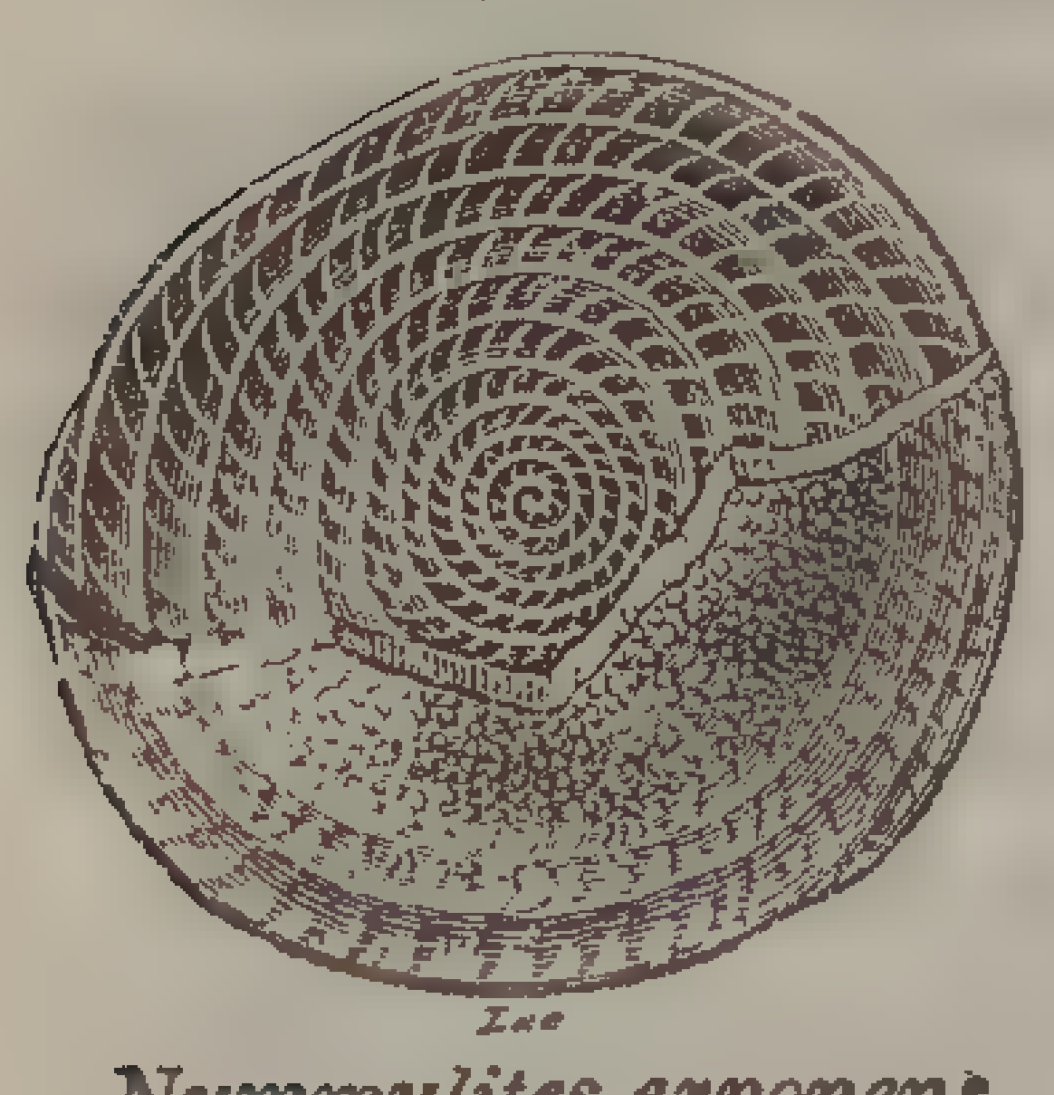
The nummulitic formation, with its characteristic fossils, plays a far more conspicuous part than any other tertiary group in the solid framework of the earth's crust, whether in Europe, Asia, or Africa. It often attains a thickness of many thousand feet, and extends from the Alps to the Carpathians, and is in full force in the north of Africa, as, for example, in Algeria and Morocco. It has also been traced from Egypt, where it was largely quarried of old for the building of the Pyramids, into Asia Minor, and across Persia by Bagdad to the mouths of the Indus. It occurs not only in Cutch, but in the mountain ranges which separate Scinde from Persia, and which form the passes leading to Caboul; and it has been followed still farther eastward into India, as far as eastern Bengal and the frontiers of China.

Fig. 242.

Nummulites Puschi, D'Archiac. Peyrehorade, Pyrenees.
a. external surface of one of the nummulites, of which longitudinal sections are seen in the limestone.
b. transverse section of same.

Dr. T. Thomson found nummulites at an elevation of no less than 16,500 feet above the level of the sea, in Western Thibet.

Fig. 243.



Nummulites exponens, Sow. Europe and India.

One of the species, which I myself found very abundant on the flanks of the Pyrenees, in a compact crystalline marble (fig. 242.) is called by M. D'Archiac *Nummulites Puschi.* The same is also very common in rocks of the same age in the Carpathians.

Another large species (see fig. 243.), *Nummulites exponens*, J. Sow., occurs not only in the South of France, near Dax, but in Germany, Italy, Asia Minor, and in Cutch; also in the mountains of Sylhet, on the frontiers of China.

In many of the distant countries above alluded to, in Cutch, for example, some of the same shells, such as, *Nerita conoidea* (fig. 240.), accompany the Nummulites as in France.

The opinion of many observers, that the nummulitic formation belongs partly to the cretaceous era, seems chiefly to have arisen from confounding an allied genus, Orbitoides, with the true Nummulite.

When we have once arrived at the conviction that the nummulitic formation occupies a middle place in the Eocene series, we are struck with the comparatively modern date to which some of the greatest revolutions in the physical geography of Europe, Asia, and Northern Africa must be referred. All the mountain chains, such as the Alps, Pyrenees, Carpathians, and Himalayas, into the composition of whose central and loftiest parts the nummulitic strata enter bodily, could have had no existence till after the Middle Eocene period. During that period the sea prevailed where these chains now rise, for nummulites and their accompanying testacea were unquestionably inhabitants of salt water. Before these events, comprising the conversion of a wide area from a sea to a continent, England had been peopled, as I before pointed out (p. 220.), by various quadrupeds, by herbivorous pachyderms, by insectivorous bats, by opossums and monkeys.

[illegible]

Almost all the extinct volcanoes which preserve any remains of their original form, or from the craters of which lava streams can be traced, are more modern than the Eocene fauna now under consideration; and besides these superficial monuments of the action of heat, Plutonic influences have worked vast changes in the texture of rocks within the same period. Some members of the nummulitic and overlying tertiary strata called *flysch* have actually been converted in the Central Alps into crystalline rocks, and transformed into marble, quartz-rock, mica-schist, and gneiss.*

EOCENE STRATA IN THE UNITED STATES.

In North America the Eocene formations occupy a large area bordering the Atlantic, which increases in breadth and importance as it is traced southwards from Delaware and Maryland to Georgia and

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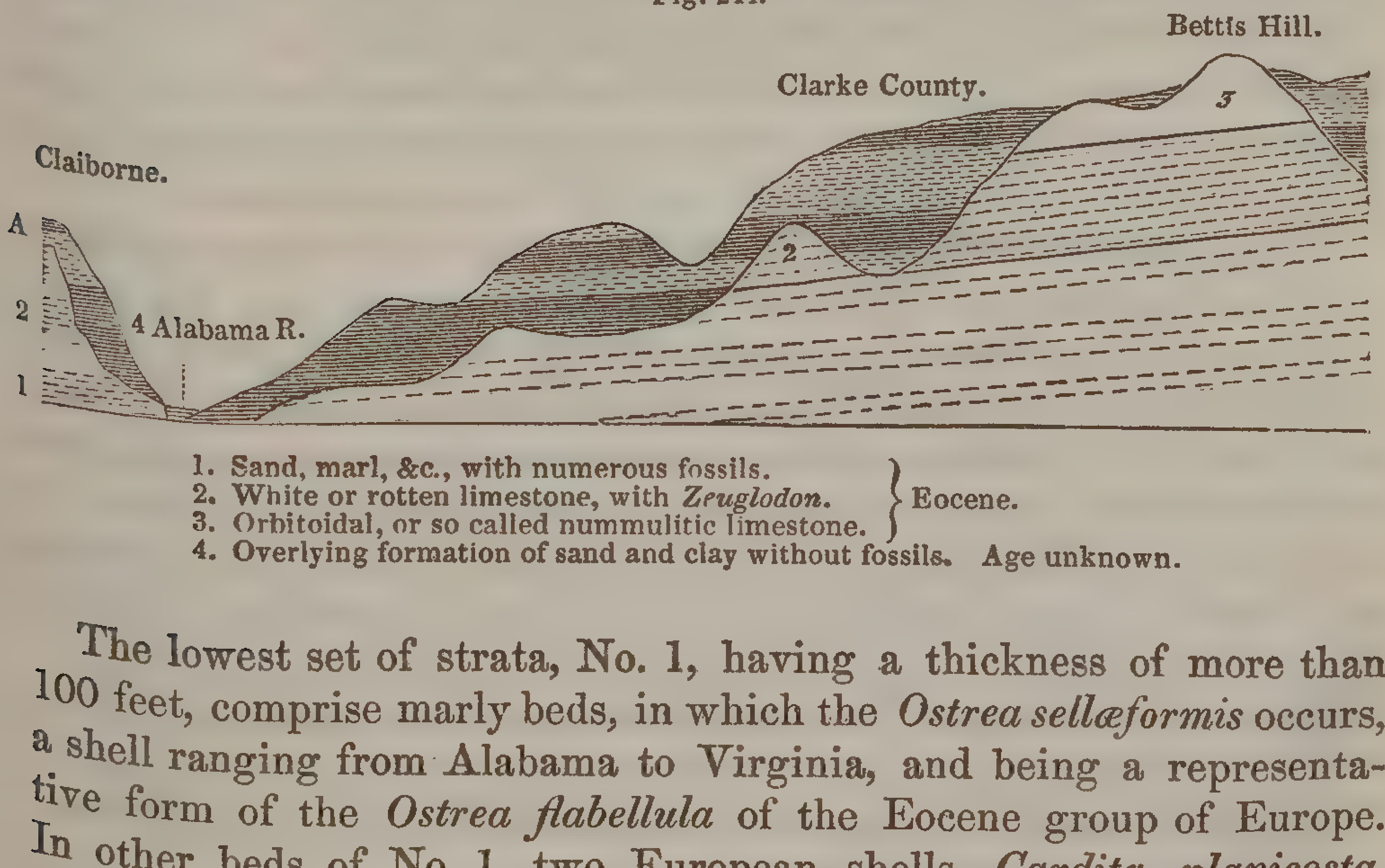
* Murchison, Quart. Journ. of Geol. Soc. vol. v., and Lyell, vol. vi. 1850. Anniversary Address.

Alabama. They also occur in Louisiana and other states both east and west of the valley of the Mississippi. At Claiborne in Alabama no less than four hundred species of marine shells, with many echinoderms and teeth of fish, characterize one member of this system. Among the shells, the *Cardita planicosta*, before mentioned (fig. 216. p. 215.), is in abundance; and this fossil, and some others identical with European species, or very nearly allied to them, make it highly probable that the Claiborne beds agree in age with the central or Bracklesham group of England, and with the calcaire grossier of Paris.*

Higher in the series is a remarkable calcareous rock, formerly called "the nummulite limestone," from the great number of discoid bodies resembling nummulites which it contains, fossils now referred by A. d'Orbigny to the genus *Orbitoides*, which has been demonstrated by Dr. Carpenter to belong to the foraminifera.† That naturalist moreover is of opinion that the Orbitoides alluded to (*O. Mantelli*) is of the same species as one found in Cutch in the Middle Eocene or nummulitic formation of India. The following section will enable the reader to understand the position of three subdivisions of the Eocene series, Nos. 1, 2, and 3, the relations of which I ascertained in Clarke County, between the rivers Alabama and Tombeckbee.

Fig. 244.



1. Sand, marl, &c., with numerous fossils.
2. White or rotten limestone, with *Zeuglodon*.
3. Orbitoidal, or so called nummulitic limestone.
} Eocene.
4. Overlying formation of sand and clay without fossils. Age unknown.

The lowest set of strata, No. 1, having a thickness of more than 100 feet, comprise marly beds, in which the *Ostrea sellæformis* occurs, a shell ranging from Alabama to Virginia, and being a representative form of the *Ostrea flabellula* of the Eocene group of Europe. In other beds of No. 1, two European shells, *Cardita planicosta*, before mentioned, and *Solarium canaliculatum*, are found, with a great many other species peculiar to America. Numerous corals, also, and the remains of placoid fish and of rays, occur, and the "swords," as they are called, of sword fishes, all bearing a great generic likeness to those of the Eocene strata of England and France.

No. 2 (fig. 244.) is a white limestone, sometimes soft and argilla-

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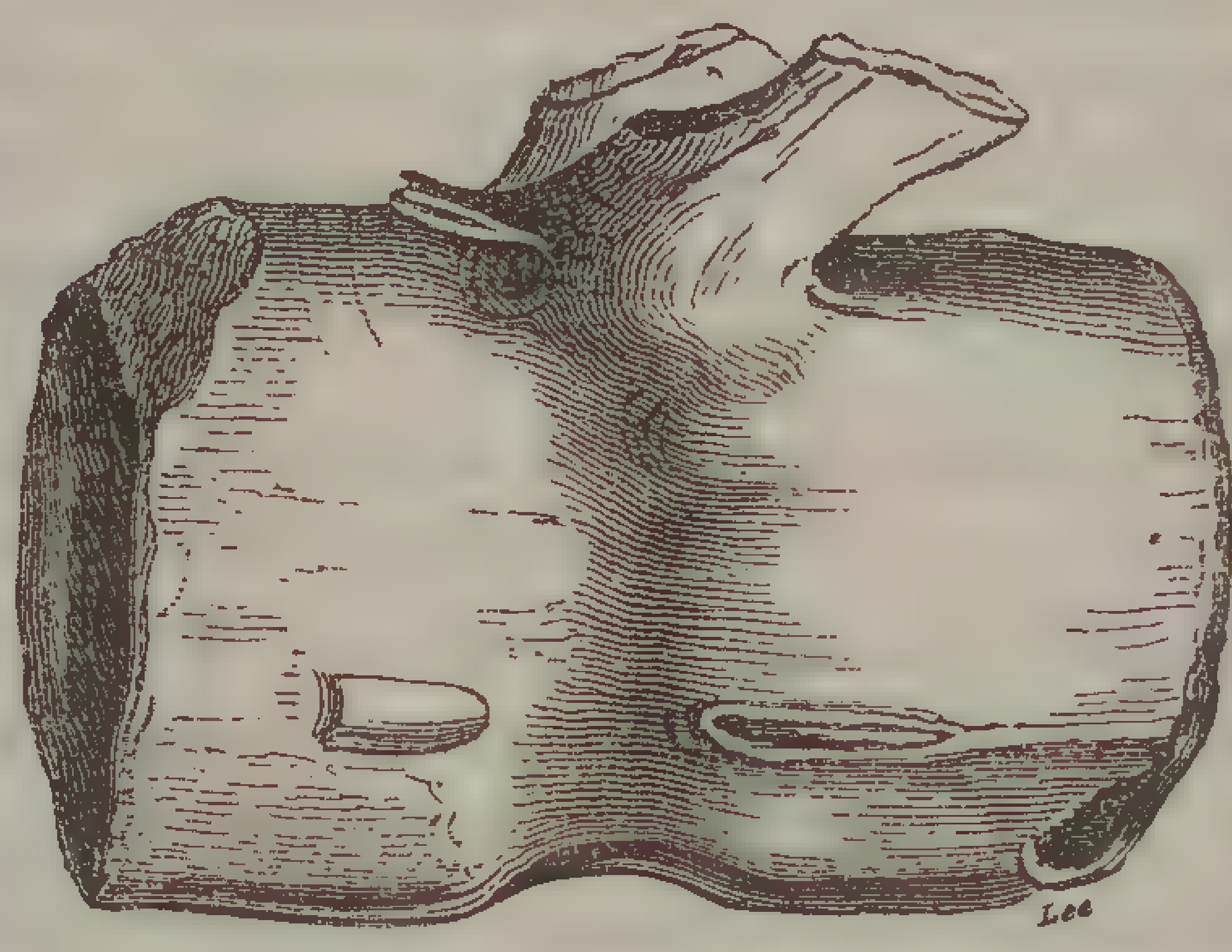
* See paper by the author, Quart. Journ. Geol. Soc. vol. iv. p. 12.; and Second Visit to the U. S. vol. ii. p. 59.

† Quart. Journ. Geol. Soc. vol. vi. p. 32.

ceous, but in parts very compact and calcareous. It contains several peculiar corals, and a large Nautilus allied to *N. ziczac;* also in its upper bed a gigantic cetacean, called *Zeuglodon* by Owen.*

Fig. 245.

Fig. 246.



Zeuglodon cetoides, Owen.
Basilosaurus, Harlan.

Fig. 245. Molar tooth, natural size.

Fig. 246. Vertebra, reduced.

The colossal bones of this cetacean are so plentiful in the interior of Clarke County as to be characteristic of the formation. The vertebral column of one skeleton found by Dr. Buckley at a spot visited by me, extended to the length of nearly 70 feet, and not far off part of another backbone nearly 50 feet long was dug up. I obtained evidence, during a short excursion, of so many localities of this fossil animal within a distance of 10 miles, as to lead me to conclude that they must have belonged to at least forty distinct individuals.

Prof. Owen first pointed out that this huge animal was not reptilian, since each tooth was furnished with double roots (see fig. 245.), implanted in corresponding double sockets; and his opinion of the cetacean nature of the fossil was afterwards confirmed by Dr. Wyman and Dr. R. W. Gibbes. That it was an extinct mammal of the whale tribe has since been placed beyond all doubt by the discovery of the entire skull of another fossil species of the same family, having the double occipital condyles only met with in mammals, and the convoluted tympanic bones which are characteristic of cetaceans.

Near the junction of No. 2 and the incumbent limestone, No. 3, next to be mentioned, are strata characterized by the following shells: *Spondylus dumosus* (*Plagiostoma dumosum*, Morton), *Pecten Poulsoni*, *Pecten perplanus*, and *Ostrea cretacea.*

No. 3 (fig. 244.) is a white limestone, for the most part made up of the *Orbitoides* of D'Orbigny before mentioned (p. 233.), formerly supposed to be a nummulite, and called *N. Mantelli*, mixed with a few lunulites some small corals and shells.† The origin, therefore, of this cream-coloured soft stone, like that of our white chalk, which it much resembles, is, I believe, due to the decomposition of these foraminifera. The surface of the country where it prevails is sometimes marked by

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* See Memoir by R. W. Gibbes, Journ. of Acad. Nat. Sci. Philad. vol. i. 1847.

† Lyell, Quart. Journ. Geol. Soc. 1847, vol. iv. p. 15.

the absence of wood, like our chalk downs, or is covered exclusively by the *Juniperus Virginiana*, as certain chalk districts in England by the yew tree and juniper.

Some of the shells of this limestone are common to the Claiborne beds, but many of them are peculiar.

It will be seen in the section (fig. 244. p. 233.) that the strata Nos. 1, 2, 3 are, for the most part, overlaid by a dense formation of sand or clay without fossils. In some points of the bluff or cliff of the Alabama river, at Claiborne, the beds Nos. 1, 2 are exposed nearly from top to bottom, whereas at other points the newer formation, No. 4, occupies the face of nearly the whole cliff. The age of this overlying mass has not yet been determined, as it has hitherto proved destitute of organic remains.

The burr-stone strata of the Southern States contain so many fossils agreeing with those of Claiborne, that it doubtless belongs to the same part of the Eocene group, though I was not fortunate enough to see the relations of the two deposits in a continuous section. Mr. Tuomey considers it as the lower portion of the series. It may, perhaps, be a form of the Claiborne beds in places where lime was wanting, and where silex, derived from the decomposition of felspar, predominated. It consists chiefly of slaty clays, quartzose sands, and loam, of a brick red colour, with layers of chert or burr-stone, used in some places for mill-stones.

CHAPTER XVII.

CRETACEOUS GROUP.

Lapse of time between the Cretaceous and Eocene periods—Whether certain formations in Belgium and France are of intermediate age—Pisolitic limestone—Divisions of the Cretaceous series in North-Western Europe—Maestricht beds—Chalk of Faxoe—White chalk—Its geographical extent and origin—Formed in an open and deep sea—How far derived from shells and corals—Single pebbles in chalk—Chalk flints,—Potstones of Horstead—Fossils of the Upper Cretaceous rocks—Echinoderms, Mollusca, Bryozoa, Sponges—Upper Greensand and Gault—Chalk of South of Europe—Hippurite limestone—Cretaceous rocks of the United States.

HAVING treated in the preceding chapters of the tertiary strata, we have next to speak of the uppermost of the secondary groups, commonly called the chalk, or the cretaceous strata, from *creta*, the Latin name for that remarkable white earthy limestone, which constitutes an upper member of the group in these parts of Europe, where it was first studied. The marked discordance in the fossils of the tertiary, as compared with the cretaceous formations, has long induced many geologists to suspect that an indefinite series of ages elapsed between the respective periods of their origin. Measured, indeed, by such a standard, that is to say, by the amount of change in the Fauna and Flora of the earth effected in the interval, the time between the cretaceous and Eocene may have been as great as that between the Eocene and recent periods, to the history of which the last seven chapters have been devoted. Several fragmentary deposits have been met with here and there, in the course of the last half century, of an age intermediate between the white chalk and the plastic clays and sands, of the Paris and London districts, monuments which have the same kind of interest to a geologist, which certain mediæval records excite when we study the history of nations. For both of them throw light on ages of darkness, preceded and followed by others of which the annals are comparatively well known to us. But these newly discovered records do not fill up the wide gap, some of them being closely allied to the Eocene, and others to the cretaceous type, while none appear as yet to possess so distinct and characteristic a fauna, as may entitle them to hold an independent place in the great chronological series.

Among the formations alluded to, the Thanet Sands of Prestwich have been sufficiently described in the last chapter, and classed as Lower Eocene. To the same tertiary series belong the Belgian formations, called by Professor Dumont, Landenian and Heersian, although these are probably of higher antiquity than the Thanet Sands. On the other hand, the Maestricht and Faxoe limestones are very closely connected with the chalk, to which also the Pisolitic limestone of France has been recently referred by high authorities.

The Lower Landenian beds of Belgium consist of marls and sands, often containing much green earth, called *glauconite*. They may be seen at Tournay, and at Angres, near Mons, and at Orp-le-Grand, Lincent, and Landen in the ancient province of Hesbaye, in Belgium, where they supply a durable building-stone, yet one so light as to be easily transported. Some few shells of the genus *Pholodamya*, *Scalaria*, and others, agree specifically with fossils of the Thanet Sands; but most of them, such as *Astarte inæquilatera*, Nyst, are peculiar. In the building-stone of Orp-le-Grand, I found a *Cardiaster*, a genus which, according to Professor E. Forbes, was previously unknown in rocks newer than the *cretaceous*.

Still older than the Lower Landenian is the marl, or calcareous glauconite of the village of Heers, near Waremme, in Belgium; also seen at Marlinne in the same district, where I have examined it. It has been sometimes classed with the cretaceous series, although as yet it has yielded no forms of a decidedly cretaceous aspect, such as Ammonite, Baculite, Belemnite, Hippurite, &c. The species of shells are for the most part new; but it contains, according to M. Hébert, *Pholodamya cuneata*, an Eocene fossil, and he assigns it with confidence to the tertiary series.

Pisolitic limestone of France.—Geologists have been still more at variance respecting the chronological relations of this rock, which is met with in the neighbourhood of Paris, and at places north, south, east, and west of that metropolis, as between Vertus and Laversines, Meudon and Montereau. It is usually in the form of a coarse yellowish or whitish limestone, and the total thickness of the series of beds already known is about 100 feet. Its geographical range, according to M. Hébert, is not less than 45 leagues from east to west, and 35 from north to south. Within these limits it occurs in small patches only, resting unconformably on the white chalk. It was originally regarded as cretaceous by M. E. de Beaumont, on the ground of its having undergone, like the white chalk, extensive denudation previous to the Eocene period; but many able paleontologists, and among others MM. C. D'Orbigny, Deshayes, and D'Archiac, disputed this conclusion, and, after enumerating 54 species of fossils, declared that their appearance was more tertiary than cretaceous. More recently, M. Hébert having found the *Pecten quadricostatus*, a cretaceous species, in this same pisolitic rock, at Montereau near Paris, and some few other fossils common to the Maestricht chalk, and to the Baculite limestone of the Cotentin, in Normandy, classed it as an upper member of the cretaceous group, an opinion since adopted by M. Alcide D'Orbigny, who has carefully examined the fossils. The *Nautilus Danicus*, fig. 249., and two or three other species found in this rock, are frequent in that of Faxoe in Denmark, but as yet no Ammonites, Hamites, Scaphites, Turrilites, Baculites, or Hippurites have been met with. The proportion of peculiar species, many of them of tertiary aspect, is confessedly large; and great aqueous erosion suffered by the white chalk, before the pisolitic limestone was formed, affords an additional indication of the two deposits being widely separated in time. The pisolitic formation, therefore, may eventually prove to be somewhat more intermediate in date between the secondary and tertiary epochs than the Maestricht rock.

It should however be observed, that all the above-mentioned strata, from the Thanet Sands to the Pisolitic limestone inclusive, and even the Maestricht rock, next to be described, exhibit marks of denudation experienced at various dates, subsequently to the consolidation of the white chalk. This fact helps us in some degree to explain the remarkable break in the sequence of European rocks, between the secondary and tertiary eras, for many strata which once existed have doubtless been swept away.

CLASSIFICATION OF THE CRETACEOUS ROCKS.

The cretaceous group has generally been divided into an Upper and a Lower series, each of them comprising several subdivisions, distinguished by peculiar fossils, and sometimes retaining a uniform mineral character throughout wide areas. The Upper series is often called familiarly *the chalk*, and the Lower *the greensand*, the last-mentioned name being derived from the green colour imparted to certain strata by grains of chloritic matter. The following table comprises the names of the subdivisions most commonly adopted:—

UPPER CRETACEOUS.

A. 1. Maestricht beds and Faxoe limestones.
2. White chalk with flints.
3. Chalk marl, or grey chalk slightly argillaceous.

4. Upper greensand, occasionally with beds of chert, and with chloritic marl (craie chloritée of French authors) in the upper portion.
5. Gault, including the Blackdown beds.

LOWER CRETACEOUS (or *Neocomian*).

B. 1. Lower greensand—Greensand, Ironsand, clay, and occasional beds of limestone (Kentish Rag).
2. Wealden beds or Weald clay and Hastings sands.*

Maestricht Beds.—On the banks of the Meuse, at Maestricht, reposing on ordinary white chalk with flints, we find an upper calcareous formation about 100 feet thick, the fossils of which are, on the whole, very peculiar, and ~~all~~ distinct from tertiary species. Some few are of species common to the inferior white chalk, among which may be mentioned *Belemnites mucronatus* (fig. 256. p. 246.) and *Pecten quadricostatus*, a shell regarded by many as a mere variety of *P. quinquecostatus* (see fig. 271.). Besides the Belemnite there are other *genera*, such as Baculite and Hamite, never found in strata newer than the cretaceous, but frequently met with in these Maestricht beds. On the other hand, *Voluta*, *Fasciolaria*, and other genera of univalve shells, usually met with only in tertiary strata, occur.

The upper part of the rock, about 20 feet thick, as seen in St. Peter's Mount, in the suburbs of Maestricht, abounds in corals and Bryozoa, often detachable from the matrix; and these beds are succeeded by a soft yellowish limestone 50 feet thick, extensively quarried from time immemorial for building. The stone below is whiter, and contains occasional nodules of grey chert or chalcedony.

M. Bosquet, with whom I examined this formation (August, 1850), pointed out to me a layer of chalk from 2 to 4 inches thick, containing green earth and numerous encrinital stems, which forms the line of demarcation between the strata containing the fossils peculiar to Maestricht and the white chalk below. The latter is distinguished by regular layers of black flint in nodules, and by several shells, such as *Terebratula carnea* (see fig. 267.), wholly wanting in beds higher than the green band. Some of the organic remains, however, for which St. Peter's Mount is celebrated, occur both above and below that parting layer, and, among others, the great marine reptile called *Mosasaurus* (see fig. 247.), a saurian supposed to have been 24 feet in length, of which the entire skull and a great part of

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* M. Alcide d'Orbigny, in his valuable work entitled Paléontologie Française, has adopted new terms for the French subdivisions of the Cretaceous Series, which, so far as they can be made to tally with English equivalents, seem explicable thus:

Danien.	Maestricht beds.
Senonien.	White chalk, and chalk marl.
Turonien.	Part of the chalk marl.
Cenomanien.	Upper greensand.
Albien.	Gault.
Aptien.	Upper part of lower greensand.
Neocomien.	Lower part of same.
Neocomien inférieur.	Wealden beds and contemporaneous marine strata.

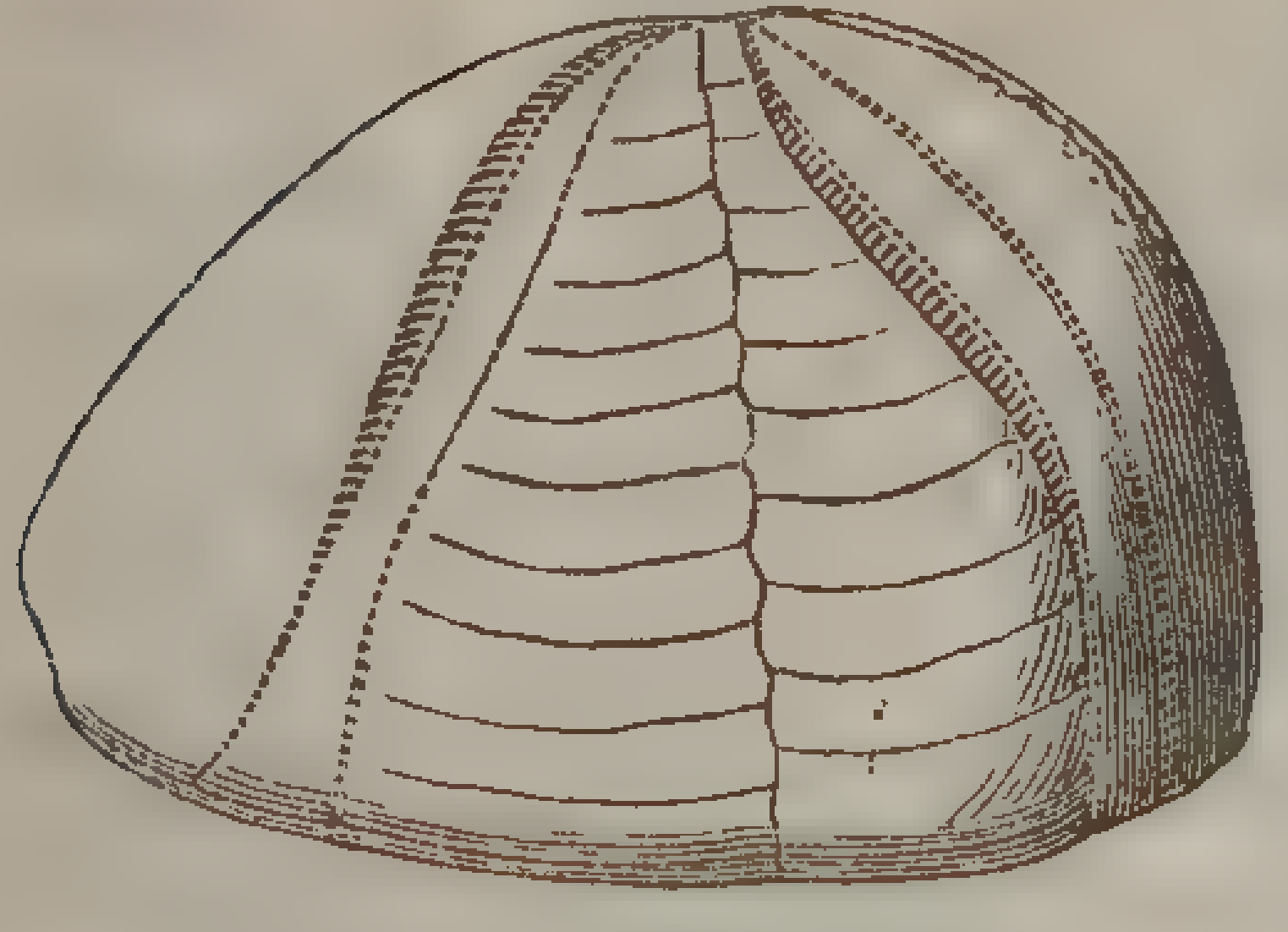
the skeleton have been found. Such remains are chiefly met with in the soft freestone, the principal member of the Maestricht beds. Among the fossils common to the Maestricht and white chalk may be instanced the echinoderm fig. 248.

Fig. 247.

Mosasaurus camperi. Original more than 3 feet long.

I saw proofs of the previous denudation of the white chalk exhibited in the lower bed of the Maestricht formation in Belgium, about 30 miles S.W. of Maestricht, at the village of Jendrain, where the base of the newer deposit consisted chiefly of a layer of well-rolled, black, chalk-flint pebbles, in the midst of which perfect specimens of *Thecidea radians* and *Belemnites mucronatus* are imbedded.

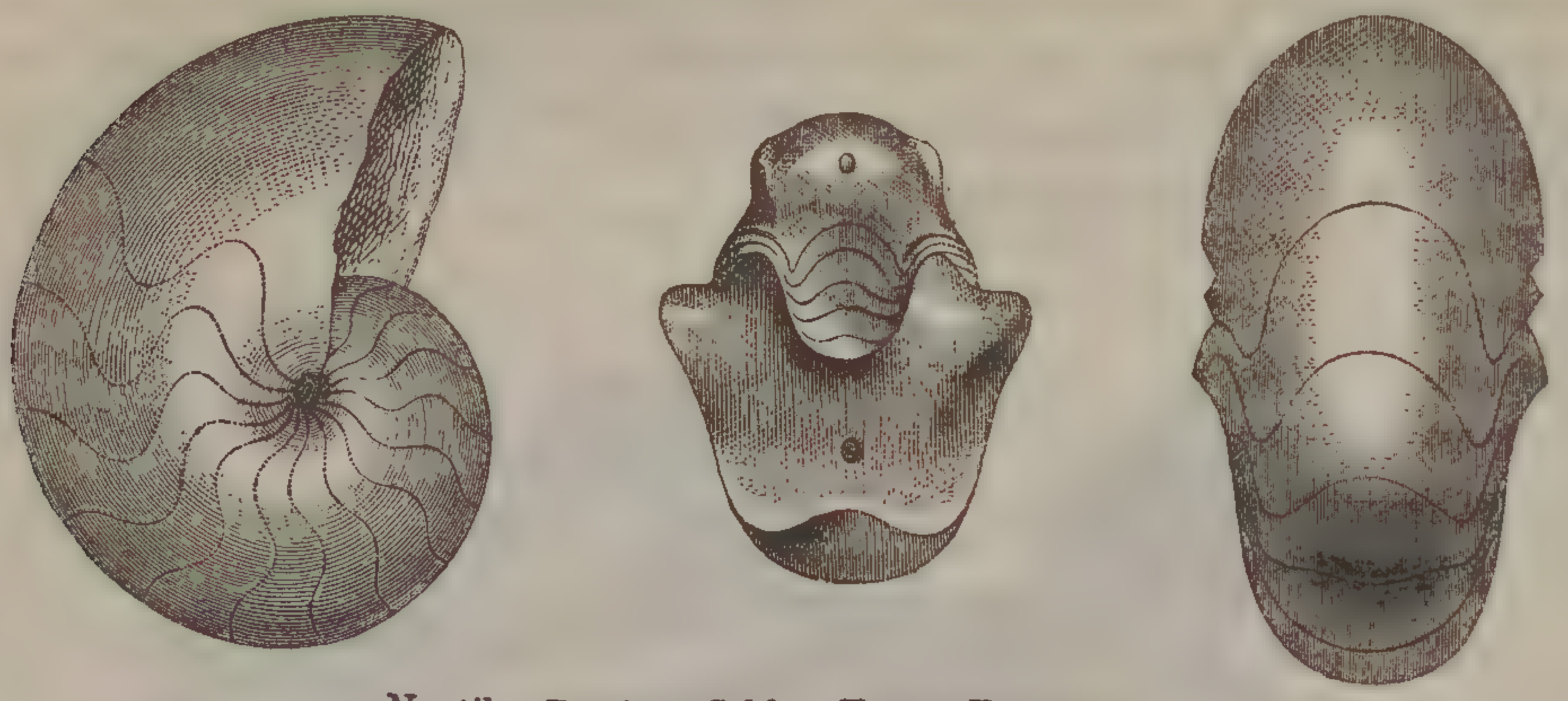
Fig. 248.



Hemipneustes radiatus, Ag.
Spatangus radiatus, Lam.
Chalk of Maestricht and white chalk.

Chalk of Faxoe. — In the island of Seeland, in Denmark, the newest member of the chalk series, seen in the sea-cliffs at Stevensklint resting on white chalk with flints, is a yellow limestone, a portion of which, at Faxoe, where it is used as a building-stone, is composed of corals, even more conspicuously than is usually observed in recent coral reefs. It has been quarried to the depth of more than 40 feet, but its thickness is unknown. The imbedded shells are chiefly casts, many of them of univalve mollusca, which are usually very rare in the white chalk of Europe. Thus, there are two species of *Cypræa*, one of *Oliva*, two of *Mitra*, four of the genus *Cerithium*, six of *Fusus*, two of *Trochus*, one *Patella*, one *Emarginula*, &c.; on the whole, more than thirty univalves, spiral or patelliform. At the same time, some of the accompanying bivalve shells, echinoderms, and zoophytes are specifically identical with fossils of the true Cretaceous series. Among the cephalopoda of Faxoe may be mentioned *Baculites Faujasii* and *Belemnites mucronatus*, shells of the white chalk. The *Nautilus Danicus* (see fig. 249.) is characteristic of this formation; and it also occurs in France in the calcaire pisolitique of Laversin (dept. of Oise).

Fig. 249.



Nautilus Danicus, Schl.—Faxoe, Denmark.

Fig. 250.

Section from Hertfordshire, in England, to Sens, in France.

The claws and entire skull of a small crab, *Brachyurus rugosus* (Schlottheim), are scattered through the Faxoe stone, reminding us of similar crustaceans enclosed in the rocks of modern coral reefs. Some small portions of this coralline formation consist of white earthy chalk; it is therefore clear that this substance must have been produced simultaneously; a fact of some importance, as bearing on the theory of the origin of white chalk; for the decomposition of such corals as we see at Faxoe is capable, we know, of forming white mud, undistinguishable from chalk, and which we may suppose to have been dispersed far and wide through the ocean, in which such reefs as that of Faxoe grew.

White chalk (see Tab. p. 237. *et seq.*).—The highest beds of chalk in England and France consist of a pure, white, calcareous mass, usually too soft for a building stone, but sometimes passing into a more solid state. It consists, almost purely, of carbonate of lime; the stratification is often obscure, except where rendered distinct by interstratified layers of flint, a few inches thick, occasionally in continuous beds, but oftener in nodules, and recurring at intervals from 2 to 4 feet distant from each other.

This upper chalk is usually succeeded, in the descending order, by a great mass of white chalk without flints, below which comes the chalk marl, in which there is a slight admixture of argillaceous matter. The united thickness of the three divisions in the south of England equals, in some places, 1000 feet.

The annexed section (fig. 250.) will show the manner in which the white chalk extends from England into France, covered by the tertiary strata described in former chapters, and reposing on lower cretaceous beds.

Geographical extent and origin of the White Chalk.—The area over which the white chalk preserves a nearly homogeneous aspect is so vast, that the earlier geologists despaired of discovering any analogous deposits of recent date. Pure chalk, of nearly uniform aspect and composition, is met with in a north-west and south-east direction, from the north of Ireland to the Crimea, a distance of about 1140 geographical miles, and in an opposite direction it extends from the south of Sweden to the south of Bordeaux, a distance of about 840 geographical miles. In Southern Russia, according to Sir R. Murchison, it is sometimes 600 feet thick, and retains the same mineral character as in France and England, with the same fossils, including *Inoceramus Cuvieri*, *Belemnites mucronatus*, and *Ostrea vesicularis*.

But it would be an error to imagine, that the chalk was ever spread out continuously over the whole of the space comprised within these limits, although it prevailed in greater or less thickness over large portions of that area. On turning to those regions of the Pacific where coral reefs abound, we find some archipelagoes of lagoon islands, such as that of the Dangerous Archipelago, for instance, and that of Radack, with several adjoining groups, which are from 1100 to 1200 miles in length, and 300 or 400 miles broad; and the space to which Flinders proposed to give the name of the Coralline Sea is still larger; for it is bounded on the east by the Australian barrier—all formed of coral rock,—on the west by New Caledonia, and on the north by the reefs of Louisiade. Although the islands in these areas may be thinly sown, the mud of the decomposing zoophytes may be scattered far and wide by oceanic currents. That this mud would resemble chalk I have already hinted when speaking of the Faxoe limestone, p. 239., and it was also remarked in an early part of this volume, that even some of that chalk, which appears to an ordinary observer quite destitute of organic remains, is nevertheless, when seen under the microscope, full of fragments of corals, bryozoa, and sponges; together with the valves of entomostraca, the shells of foraminifera, and still more minute infusoria. (See p. 26.)

Now it had been often suspected, before these discoveries, that white chalk might be of animal origin, even where every trace of organic structure has vanished. This bold idea was partly founded on the fact, that the chalk consisted of carbonate of lime, such as would result from the decomposition of testacea, echini, and corals; and partly on the passage observable between these fossils when half decomposed and chalk. But this conjecture seemed to many naturalists quite vague and visionary, until its probability was strengthened by new evidence brought to light by modern geologists.

We learn from Captain Nelson, that, in the Bermuda Islands, and in the Bahamas, there are many basins or lagoons almost surrounded and inclosed by reefs of coral. At the bottom of these lagoons a soft white calcareous mud is formed, not merely from the comminution of corallines (or calcareous plants) and corals, together with the exuviæ of foraminifera, mollusks, echinoderms, and crustaceans, but also, as Mr. Darwin observed upon studying the coral islands of the Pacific, from the fæcal matter ejected by echinoderms, conchs, and coral-eating fish. In the West Indian seas, the conch (*Strombus gigas*) adds largely to the chalky mud by means of its fæcal pellets, composed of minute grains of soft calcareous matter, exhibiting some organic tissue. Mr. Darwin describes gregarious fishes of the genus *Scarus*, seen through the clear waters of the coral regions of the Pacific browsing quietly in great numbers on living corals, like grazing herds of graminivorous quadrupeds. On opening their bodies, their intestines were found to be filled with impure chalk. This circumstance is the more in point, when we recollect how the fossilist was formerly puzzled by meeting, in chalk, with certain bodies, called "larch-cones," which were afterwards recognized by Dr. Buckland to be the excrement of fish. Such spiral coprolites (fig. 251.), like the scales and bones of fossil fish in the chalk, are composed chiefly of phosphate of lime.

Fig. 251.

Coprolites of fish, called *Iulo cido-copri*, from the chalk.

In the Bahamas, the angel-fish, and the unicorn or trumpet-fish, and many others, feed on shell-fish, or on corals.

The mud derived from the sources above mentioned may be actually seen in the Maldiva Atolls to be washed out of the lagoons through narrow openings leading from the lagoon to the ocean, and the waters of the sea are discoloured by it for some distance. When dried, this mud is very like common chalk, and might probably be made by a moderate pressure to resemble it still more closely.*

Mr. Dana, when describing the elevated coral reef of Oahu, in the Sandwich Islands, says that some varieties of the rock consist of aggregated shells, imbedded in a compact calcareous base as firm in texture as any secondary limestone; while others are like chalk, having its colour, its earthy fracture, its soft homogeneous texture, and being an equally good writing material. The same author describes, in many growing coral reefs, a similar formation of modern chalk, undistinguishable from the ancient.† The extension, over a wide submarine area, of the calcareous matrix of the chalk, as well as of the imbedded fossils, would take place more readily in consequence of the low specific gravity of the shells of mollusca and zoophytes, when compared with ordinary sand and mineral matter. The mud also derived from their decomposition would be much lighter than argillaceous and inorganic mud, and very easily transported by currents, especially in salt water.

Single pebbles in chalk.—The general absence of sand and pebbles in the white chalk has been already mentioned; but the occurrence here and there, in the south-east of England, of a few isolated peb-

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* See Nelson, Geol. Trans. 1837, vol. v. p. 108.; and Geol. Quart. Journ. 1853, p. 200.

† Geol. of U. S. Exploring Exped. p. 252. 1849.

bles of quartz and green schist, some of them 2 or 3 inches in diameter, has justly excited much wonder. If these had been carried to the spots where we now find them by waves or currents from the lands once bordering the cretaceous sea, how happened it that no sand or mud were transported thither at the same time? We cannot conceive such rounded stones to have been drifted like erratic blocks by ice (see ch. x. and xi.), for that would imply a cold climate in the Cretaceous period; a supposition inconsistent with the luxuriant growth of large chambered univalves, numerous corals, and many fish, and other fossils of tropical forms.

Now in Keeling Island, one of those detached masses of coral which rise up in the wide Pacific, Captain Ross found a single fragment of greenstone, where every other particle of matter was calcareous: and Mr. Darwin concludes that it must have come there entangled in the roots of a large tree. He reminds us that Chamisso, the distinguished naturalist who accompanied Kotzebue, affirms, that the inhabitants of the Radack archipelago, a group of lagoon islands in the midst of the Pacific, obtained stones for sharpening their instruments by searching the roots of trees which are cast up on the beach.*

It may perhaps be objected, that a similar mode of transport cannot have happened in the cretaceous sea, because fossil wood is very rare in the chalk. Nevertheless wood is sometimes met with, and in the same parts of the chalk where the pebbles are found, both in soft stone and in a silicified state in flints. In these cases it has often every appearance of having been floated from a distance, being usually perforated by boring-shells, such as the *Teredo* and *Fistulana*.†

The only other mode of transport which suggests itself is sea-weed. Dr. Beck informs me that in the Lym-Fiord, in Jutland, the *Fucus vesiculosus*, often called kelp, sometimes grows to the height of 10 feet, and the branches rising from a single root form a cluster several feet in diameter. When the bladders are distended, the plant becomes so buoyant as to float up loose stones several inches in diameter, and these are often thrown by the waves high up on the beach. The *Fucus giganteus* of Solander, so common in Terra del Fuego, is said by Captain Cook to attain the length of 360 feet, although the stem is not much thicker than a man's thumb. It is often met with floating at sea, with shells attached, several hundred miles from the spots where it grew. Some of these plants, says Mr. Darwin, were found adhering to large loose stones in the inland channels of Terra del Fuego, during the voyage of the Beagle in 1834; and that so firmly, that the stones were drawn up from the bottom into the boat, although so heavy that they could scarcely be lifted in by one person. Some fossil sea-weeds have been found in the Cretaceous formation, but none, as yet, of large size.

But we must not imagine that because pebbles are so rare in the

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* Darwin, p. 549. Kotzebue's First Voyage, vol. iii. p. 155.

† Mantell, Geol. of S. E. of England, p. 96.

white chalk of England and France there are no proofs of sand, shingle, and clay having been accumulated contemporaneously even in European seas. The siliceous sandstone, called "upper quader" by the Germans, overlies white argillaceous chalk or "pläner-kalk," a deposit resembling in composition and organic remains the chalk marl of the English series. This sandstone contains as many fossil shells common to our white chalk as could be expected in a sea-bottom formed of such different materials. It sometimes attains a thickness of 600 feet, and by its jointed structure and vertical precipices, plays a conspicuous part in the picturesque scenery of Saxon Switzerland, near Dresden.

Chalk Flints. — The origin of the layers of flint, whether in continuous sheets or in the form of nodules, is more difficult to explain than is that of the white chalk. No such siliceous masses are as yet known to accompany the aggregation of chalky mud in modern coral reefs. The flint abounds mostly in the uppermost chalk, and becomes more rare or is entirely wanting as we descend; but this rule does not hold universally throughout Europe. Some portion of the flint may have been derived from the decomposition of sponges and other zoophytes provided with siliceous skeletons; for it is a fact, that siliceous spiculæ, or the minute bones of sponges, are often met with in flinty nodules, and may have served at least as points of attraction to some of the siliceous matter when it was in the act of separating from chalky mud during the process of solidification. But there are other copious sources before alluded to, whence the waters of the ocean derive a constant supply of silex in solution, such as the decomposition of felspathic rock (see p. 42.), also mineral springs rising up in the bed of the sea, especially those of a high temperature; since their waters, if chilled when first mingling with the sea, would readily precipitate siliceous matter (see above, p. 42.). Nevertheless, the occurrence in the white chalk of beds of nodular or tabular flint at so many distinct levels, implies a periodical action throughout wide oceanic areas not easily accounted for. It seems as if there had been time for each successive accumulation of calcareo-siliceous mud to become partially consolidated, and for a re-arrangement of its particles to take place (the heavier silex sinking to the bottom) before the next stratum was superimposed; a process formerly suggested by Dr. Buckland.*

A more difficult enigma is presented by the occurrence of certain huge flints, or potstones as they are called in Norfolk, occurring singly, or arranged in nearly continuous columns at right angles to the ordinary and horizontal layers of small flints. I visited, in the year 1825, an extensive range of quarries then open on the river Bure, near Horstead, about six miles from Norwich, which afforded a continuous section, a quarter of a mile in length, of white chalk, exposed to the depth of 26 feet, and covered by a thick bed of gravel. The potstones, many of them pear-shaped, were usually

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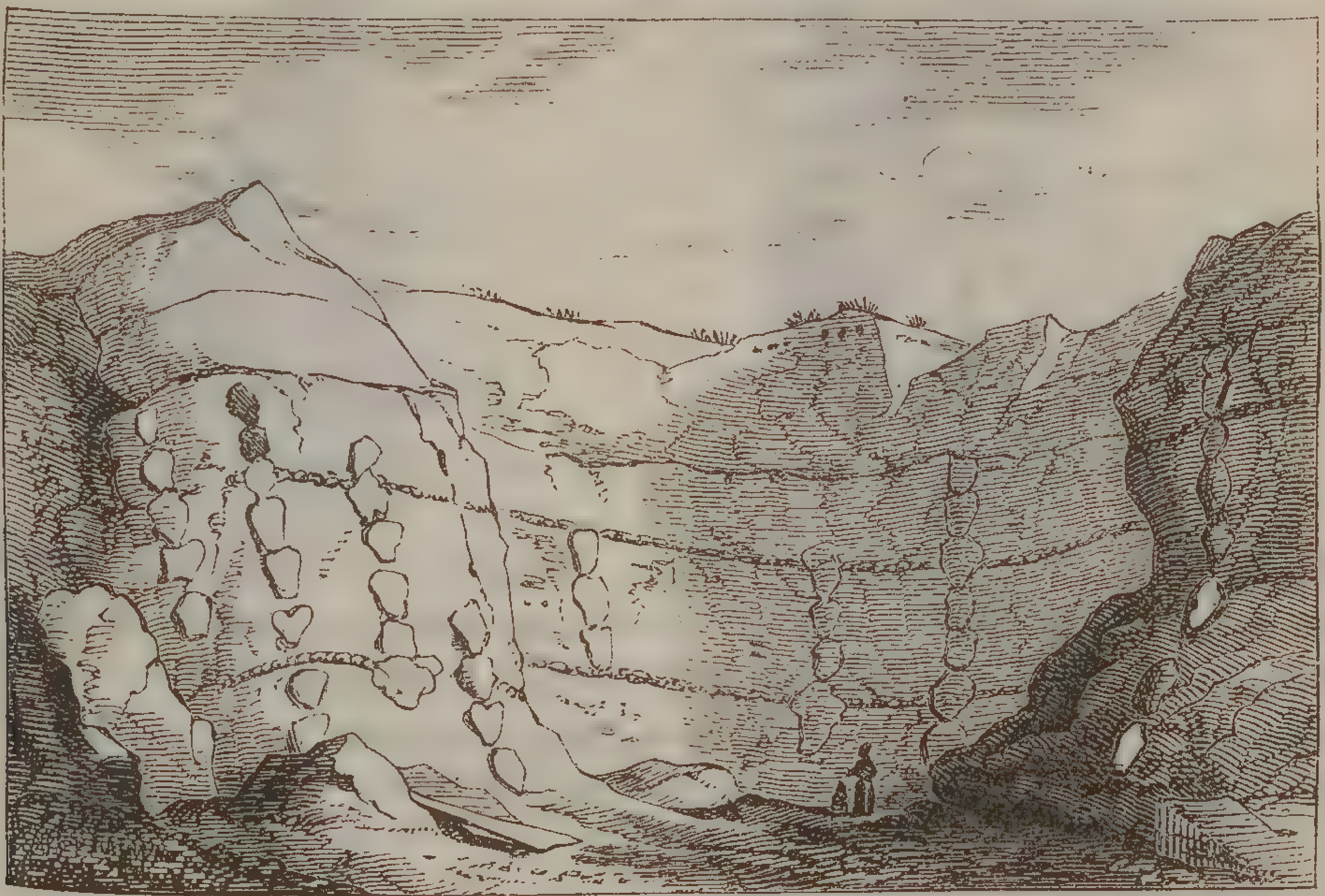
* Geol. Trans., First series, vol. iv. p. 413.

about three feet in height, and one foot in their transverse diameter, placed in vertical rows, like pillars at irregular distances from each other, but usually from 20 to 30 feet apart, though sometimes nearer together, as in the above sketch. These rows did not terminate downwards in any instance which I could examine, nor upwards, except at the point, where they were cut off abruptly by the bed of gravel. On breaking open the potstones, I found an internal cylindrical nucleus of pure chalk, much harder than the ordinary surrounding chalk, and not crumbling to pieces like it, when exposed to the winter's frost. At the distance of half a mile, the vertical piles of potstones were much farther apart from each other. Dr. Buckland has described very similar phenomena as characterizing the white chalk on the north coast of Antrim, in Ireland.*

Fig. 252.

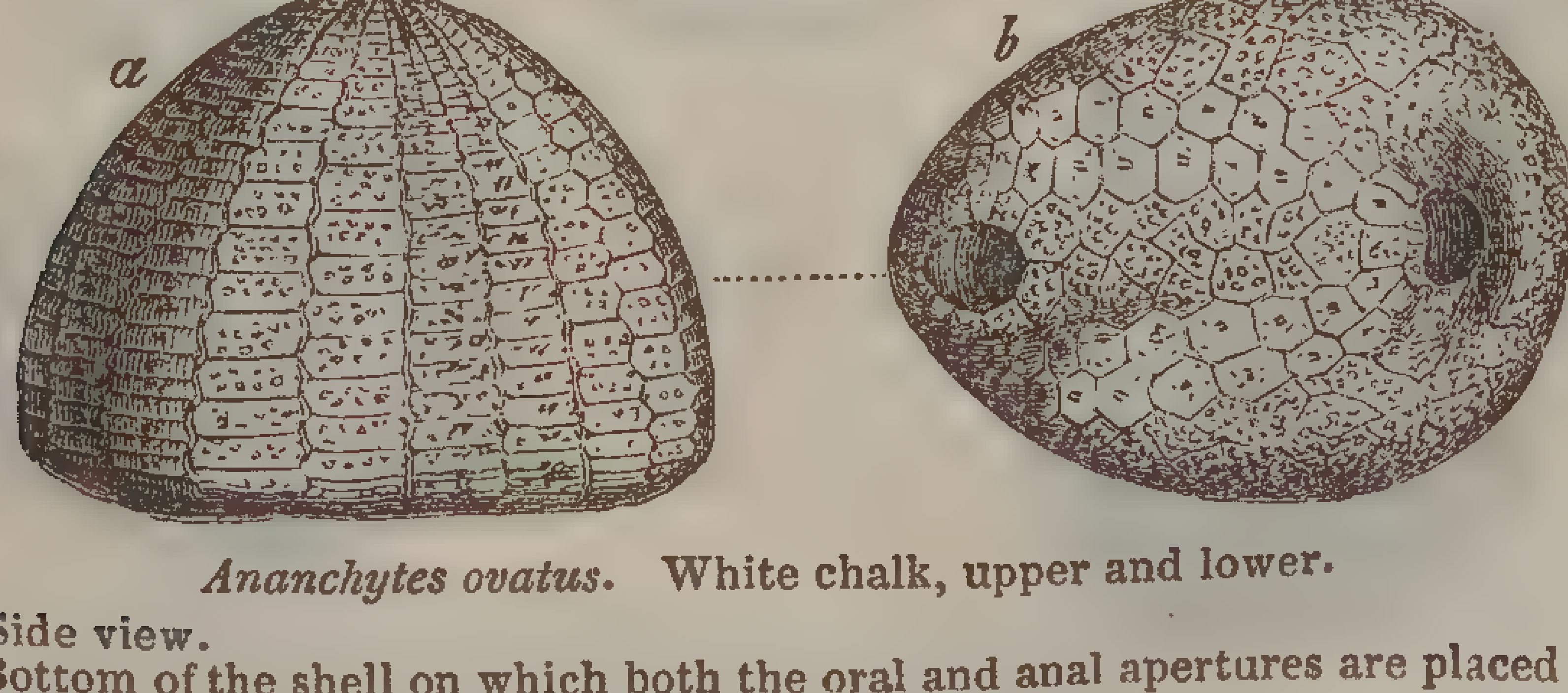


From a drawing by Mrs. Gunn.
View of a chalk pit at Horstead, near Norwich, showing the position of the potstones.

FOSSILS OF THE UPPER CRETACEOUS ROCKS.

Among the fossils of the white chalk, echinoderms are very nu-

Fig. 253.



Ananchytes ovatus. White chalk, upper and lower.
a. Side view.
b. Bottom of the shell on which both the oral and anal apertures are placed; the anal being more round, and at the smaller end.

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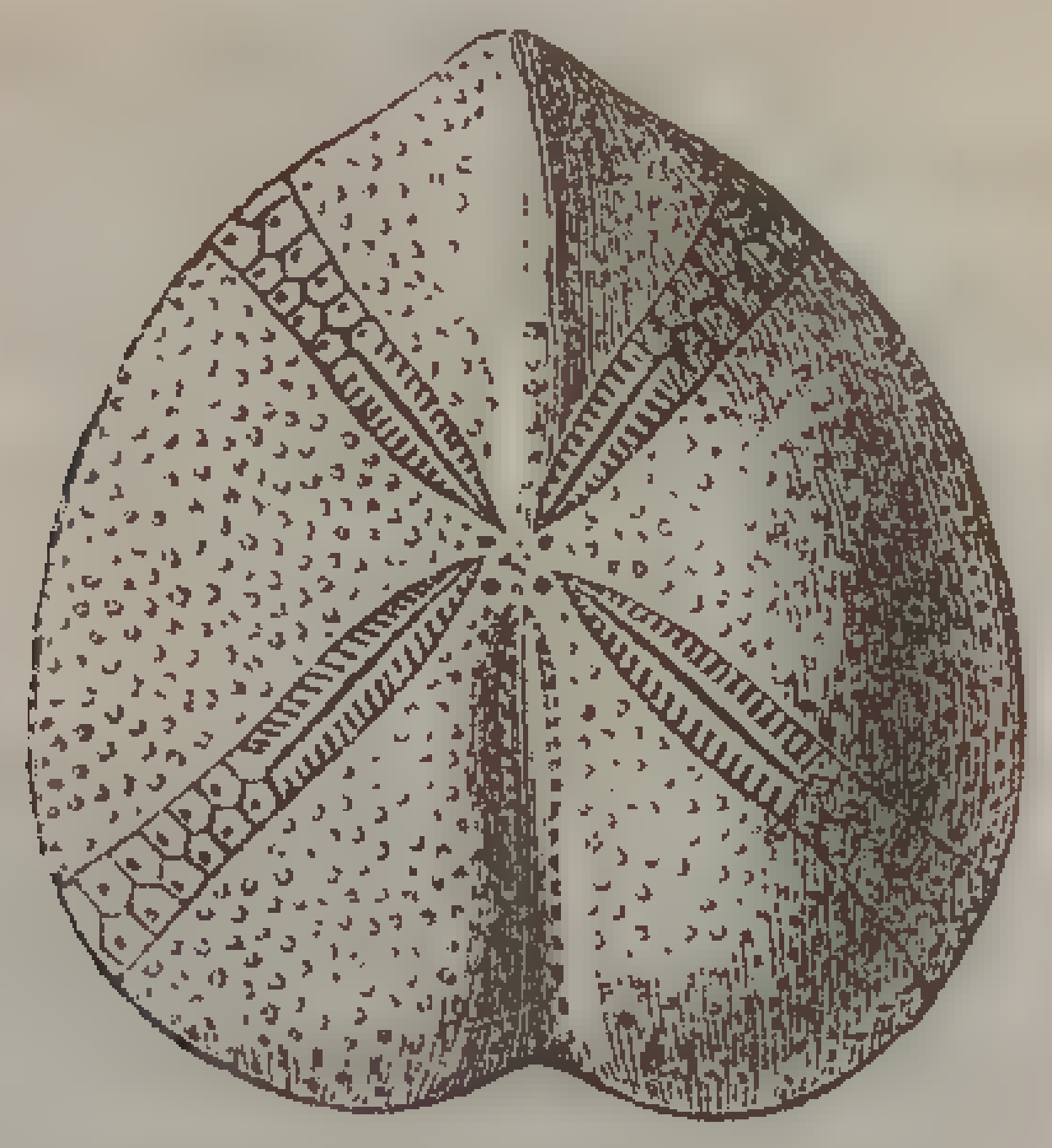
* Geol. Trans., First series, vol. iv. p. 413., "On Paramoudra, &c."

merous; and some of the genera, like *Ananchytes* (see fig. 253.), are exclusively cretaceous. Among the Crinoidea, the *Marsupite* (fig. 260.) is a characteristic genus. Among the mollusca, the cephalopoda, or chambered univalves, of the genera Ammonite, Scaphite, Belemnite, (fig. 256.) Baculite, (257.—259.) and Turrilite, (262, 263.) with other allied forms, present a great contrast to the testacea of the same class in the tertiary and recent periods.

Fig. 254.



Micraster cor anguinum.
White chalk.

Fig. 255.

Galerites albogalerus, Lam.
White chalk.

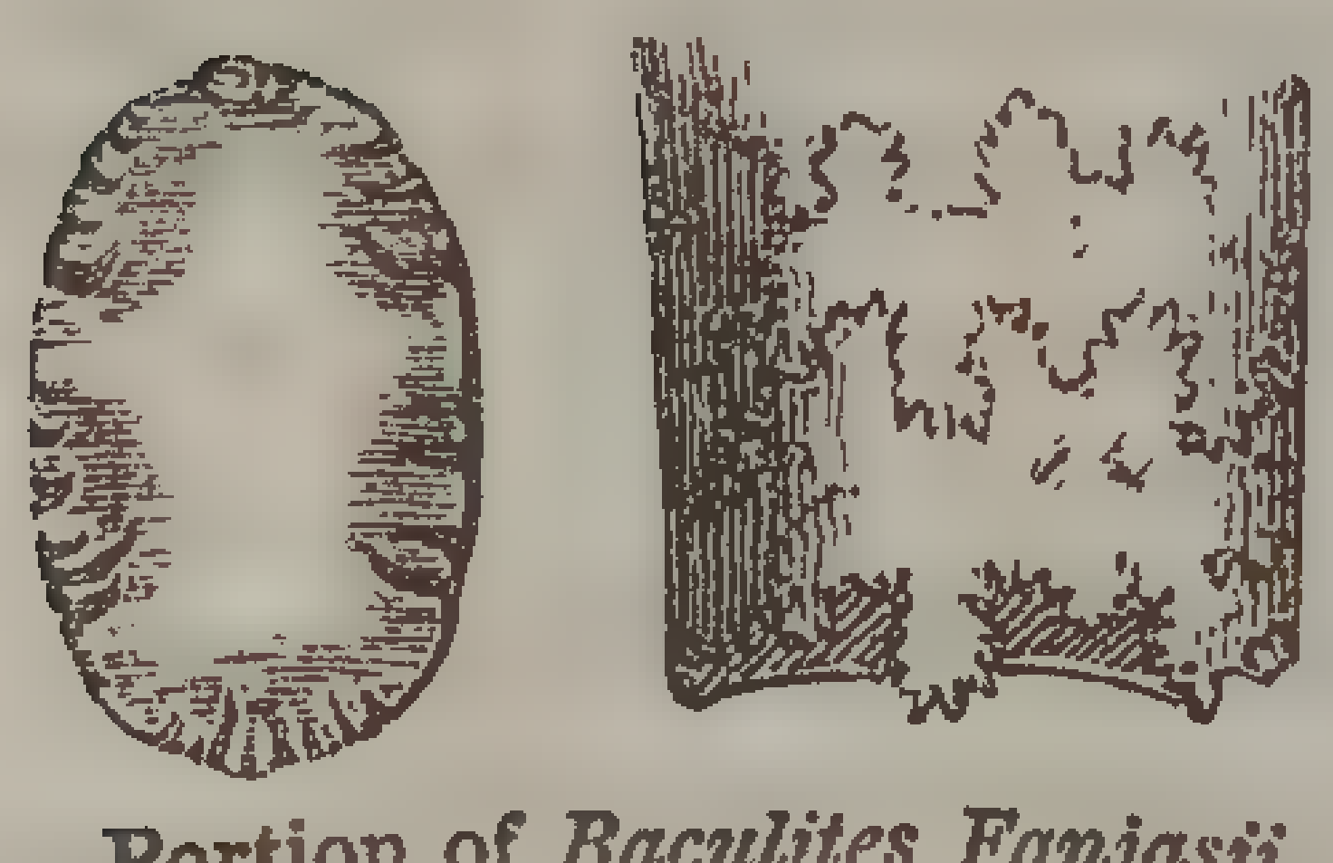
Fig. 256.

a. Belemnites mucronatus.
b. Same, showing internal structure. Maestricht, Faxoe, and white chalk.

Fig. 257.

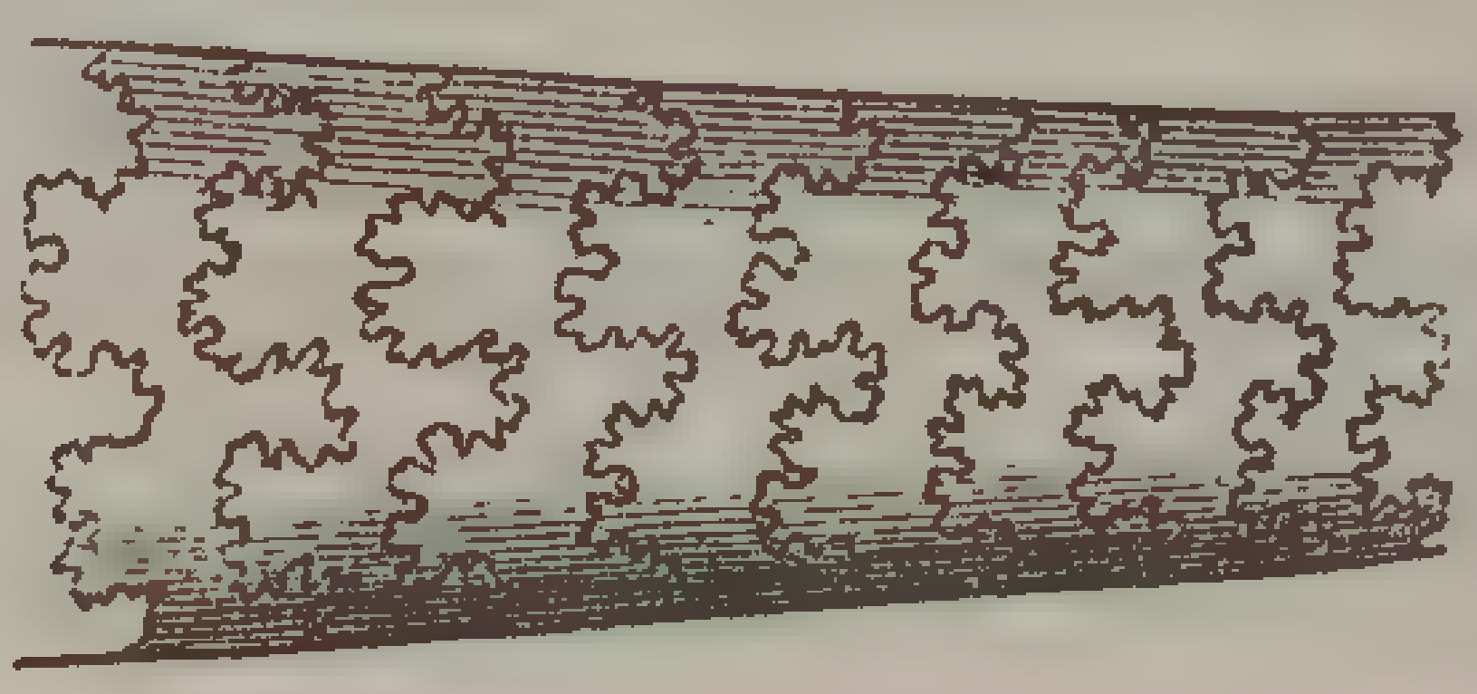
Baculites anceps. Upper green sand, or chloritic marl, *craie chloritée.* France.
A. D'Orb. Terr. Cret.

Fig. 258.



Portion of *Baculites Fanjasii.*
Maestricht and Faxoe beds and white chalk.

Fig. 259.



Portion of *Baculites anceps.*
Maestricht and Faxoe beds and white chalk.

Fig. 260.

Marsupites Milleri.
White chalk.

Fig. 261.

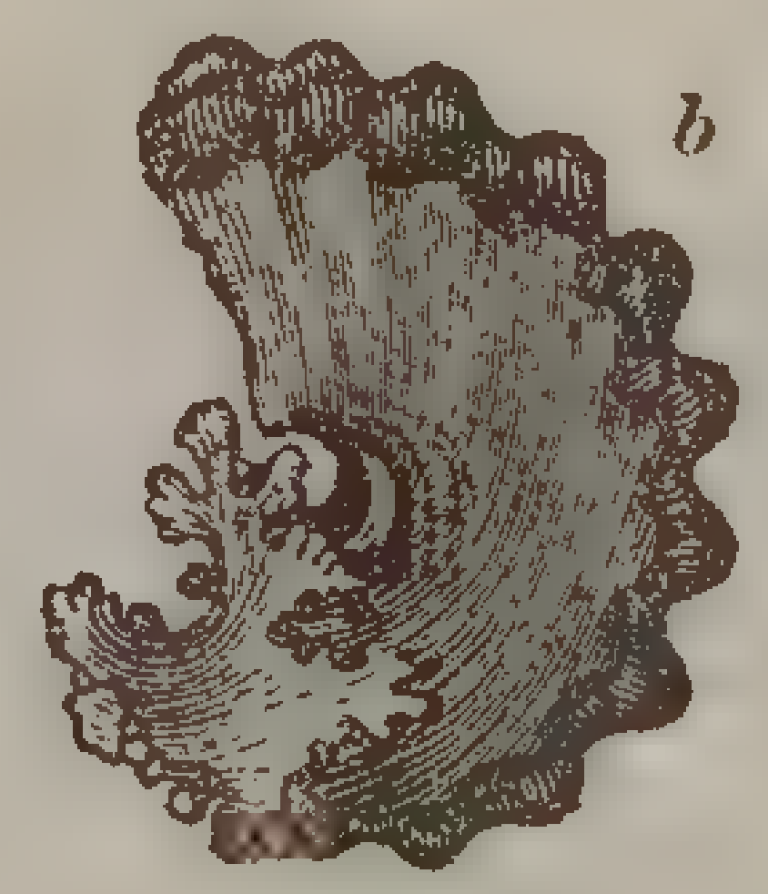
Scaphites æqualis. Chloritic marl of Upper Green Sand, Dorsetshire.

Fig. 262.

Turrilites costatus.
Chalk

Fig. 263.

a. Fragment of *Turrilites costatus*,
Chalk marl.



b. Same, showing the indented border
of the partition of the chambers.

Among the brachiopoda in the white chalk, the *Terebratulæ* are very abundant. These shells are known to live at the bottom of the sea, where the water is tranquil and of some depth (see figs. 264. 265, 266, 267, 268.). With these are associated some forms of oyster (see figs. 275, 276, 277.), and other bivalves (figs. 269, 270, 271, 272, 273.).

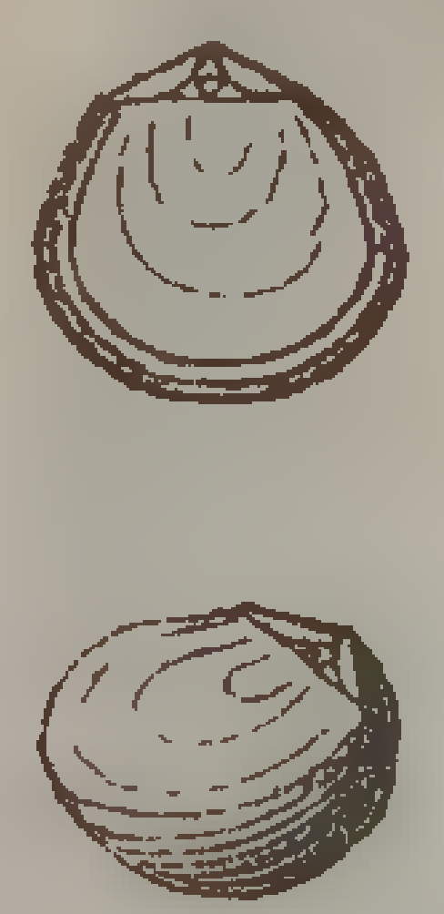
Fig. 264.

Terebratula Defrancii.
Upper white chalk.

Fig. 265.

Terebratula octoplicata.
(Var. of *T. plicatilis.*)
Upper white chalk.

Fig. 266.



Terebratula pumilus.
(*Magas pumilus*, Sow.)
Upper white chalk.

Fig. 267.

Terebratula carnea.
Upper white chalk.

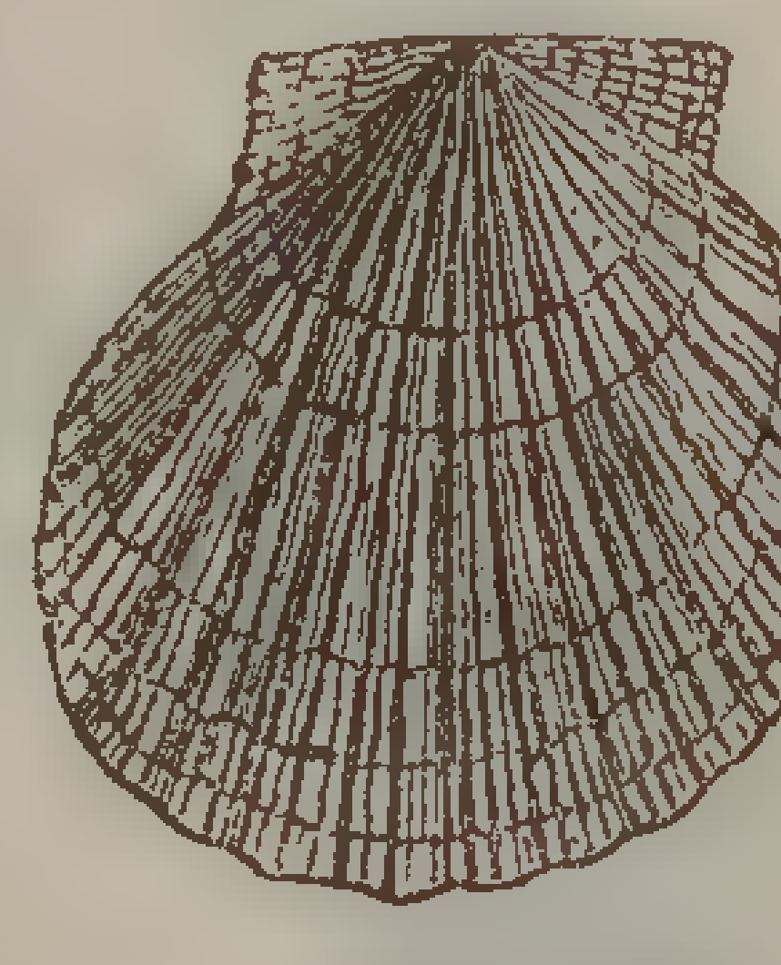
Fig. 268.

Terebratula biplicata,
Sow. Upper cretaceous.

Fig. 269

Crania Parisiensis,
inferior or attached
valve.
Upper white chalk.

Fig. 270.



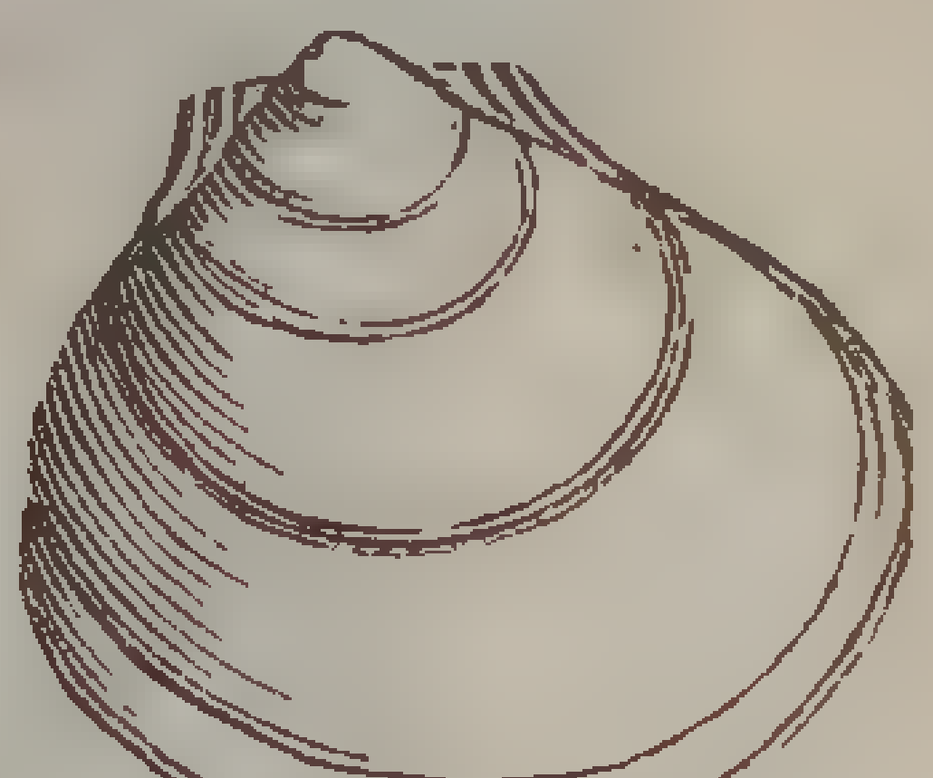
Pecten Beaveri, reduced to
one-third diameter.
Lower white chalk and chalk
marl. Maidstone.

Among the bivalve mollusca, no form marks the cretaceous era in Europe, America, and India in a more striking manner than the extinct genus *Inoceramus* (*Catillus* of Lam.: see fig. 274.), the shells of which are distinguished by a fibrous texture, and are often met with in fragments, having, probably, been extremely friable.

Fig. 271.

Pecten 5-costatus.
White chalk, upper and lower greensands.

Fig. 272.



Plagiostoma Hoperi, Sow.
Syn. *Lima Hoperi.*
White chalk and upper greensand.

Fig. 273.

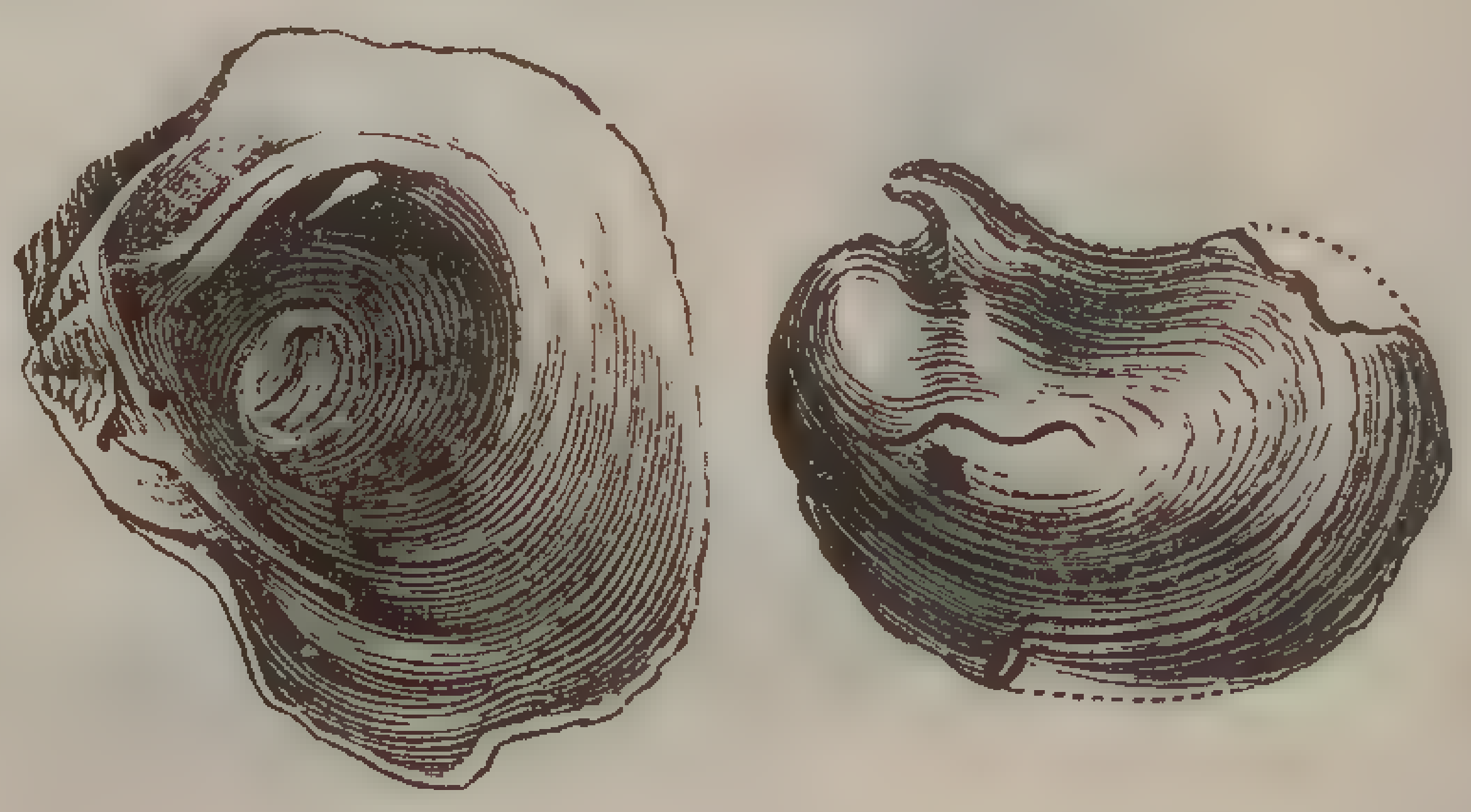
Plagiostoma spinosum, Sow.
Syn. *Spondylus spinosus.*
Upper white chalk.

Of the singular family called *Rudistes*, by Lamarck, hereafter to be mentioned as extremely characteristic of the chalk of Southern Europe, a single representative only (fig. 278.) has been discovered in the white chalk of England.

Fig. 274.

Inoceramus Lamarckii.
Syn. *Catillus Lamarckii.*
White Chalk (Dixon's Geol. Sussex. Tab. 28. fig. 29.).

Fig. 275.

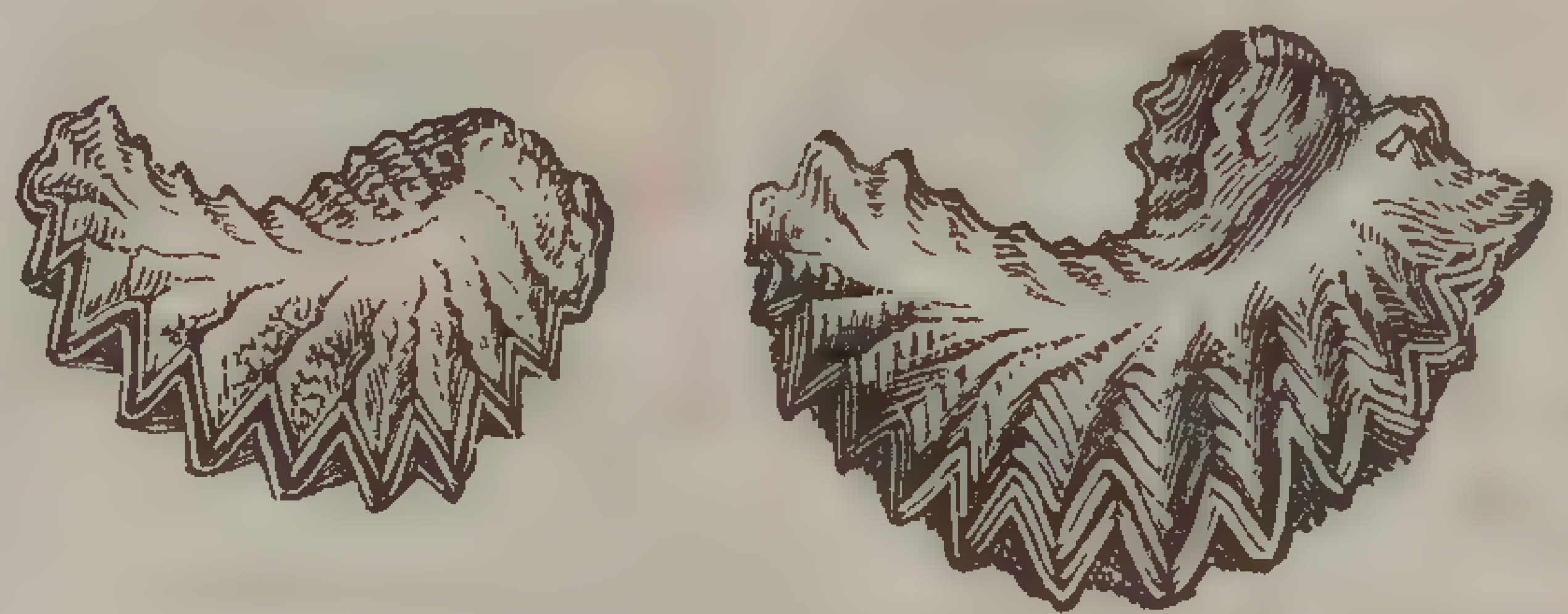


Ostrea vesicularis. Syn. *Gryphæa globosa.*
Upper chalk and upper greensand.

Fig. 276.

Ostrea columba.
Syn. *Gryphæa columba.*
Upper greensand.

Fig. 277.



Ostrea carinata. Chalk marl, upper and lower greensand.

Fig. 278.

Fig. 279.

Fig. 280.

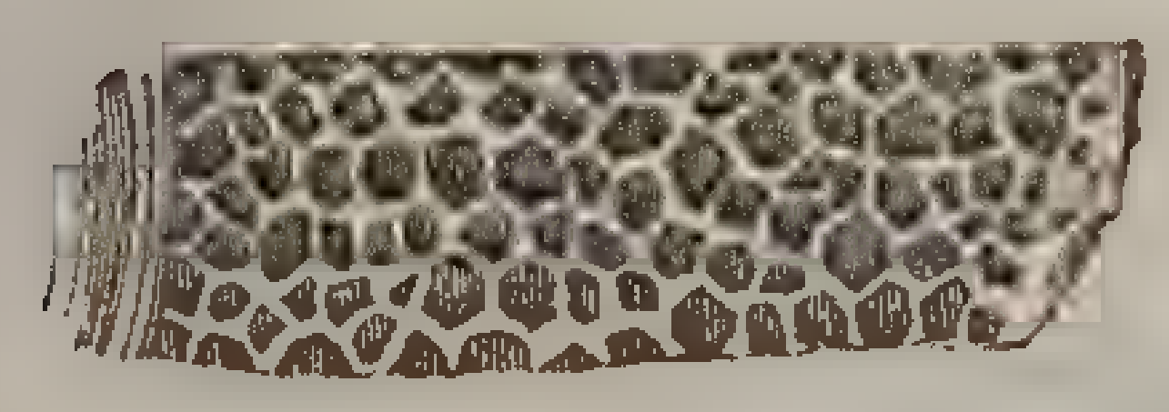


Fig. 281.

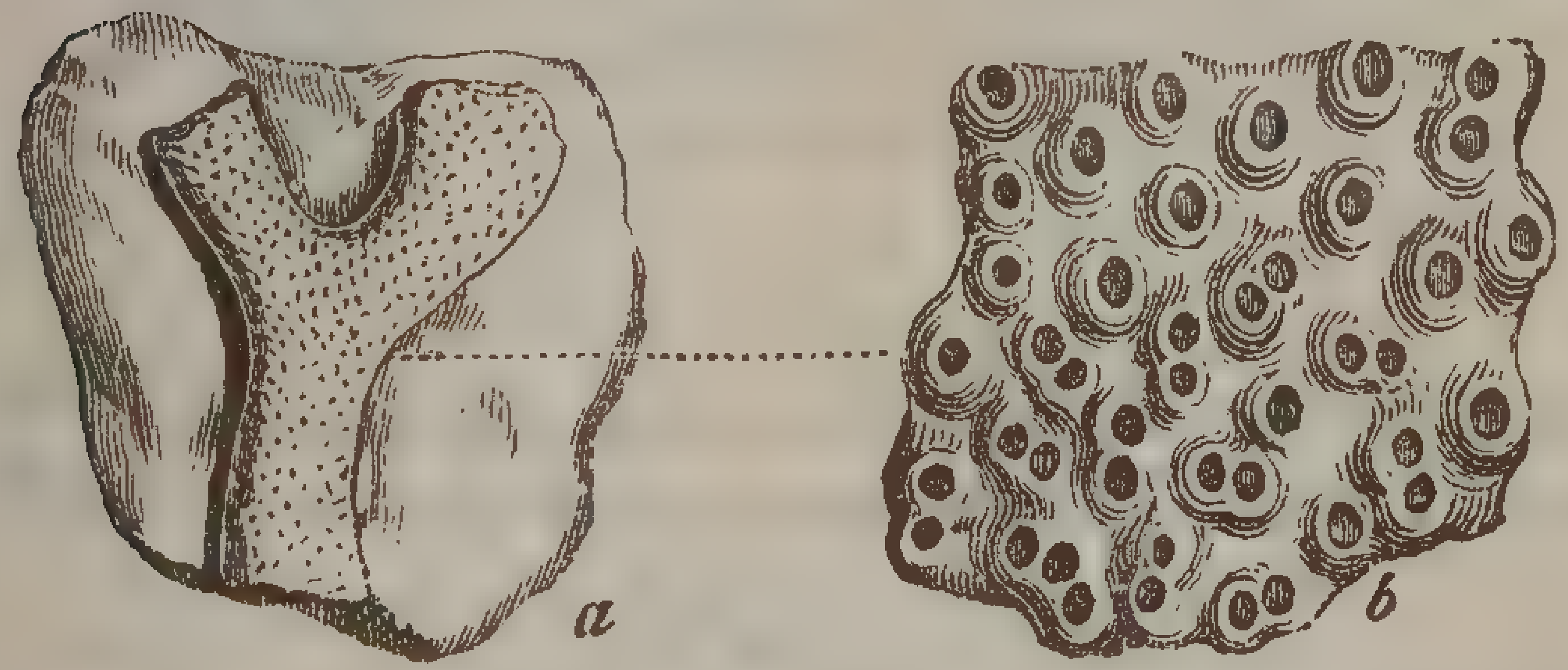
Radiolites Mortoni, Mantell. Houghton, Sussex. White chalk.
Diameter one-seventh nat. size.

Fig. 278. Two individuals deprived of their upper valves, adhering together.
279. Same seen from above.
280. Transverse section of part of the wall of the shell, magnified to show the structure.
281. Vertical section of the same.

On the side where the shell is thinnest, there is one external furrow and corresponding internal ridge, *a*, *b*, figs. 278, 279.; but they are usually less prominent than in these figures. This species was first referred by Mantell to *Hippurites*, afterwards to the genus *Radiolites*. I have never seen the upper valve. The specimen above figured was discovered by the late Mr. Dixon.

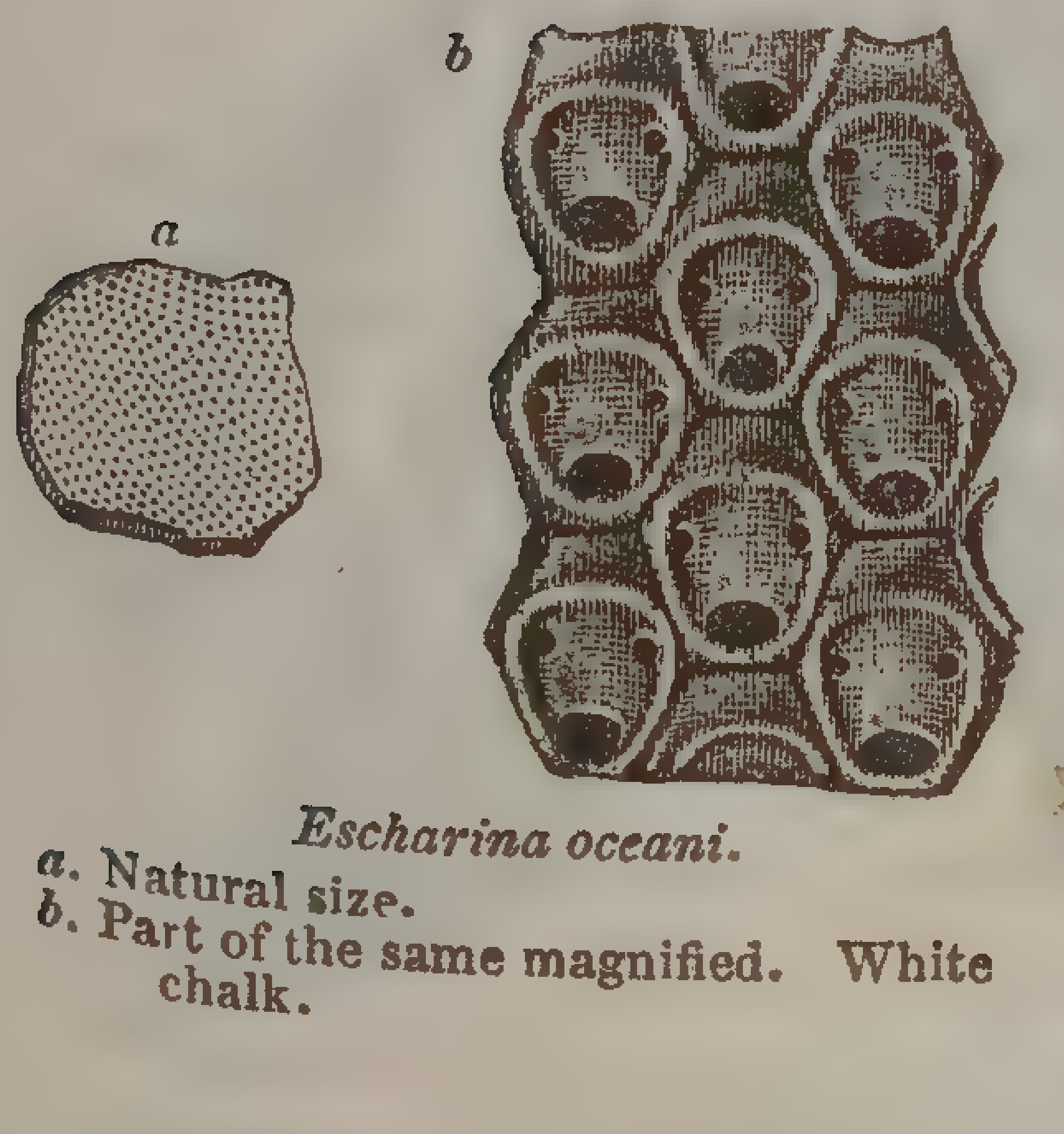
With these mollusca are associated many Bryozoa, such as *Eschara* and *Escharina* (figs. 282, 283.), which are alike marine, and, for the most part, indicative of a deep sea. These and other organic bodies, especially sponges, such as *Ventriculites* (fig. 284.

Fig. 282.



Eschara disticha.
a. Natural size.
b. Portion magnified.
White chalk.

Fig. 283.



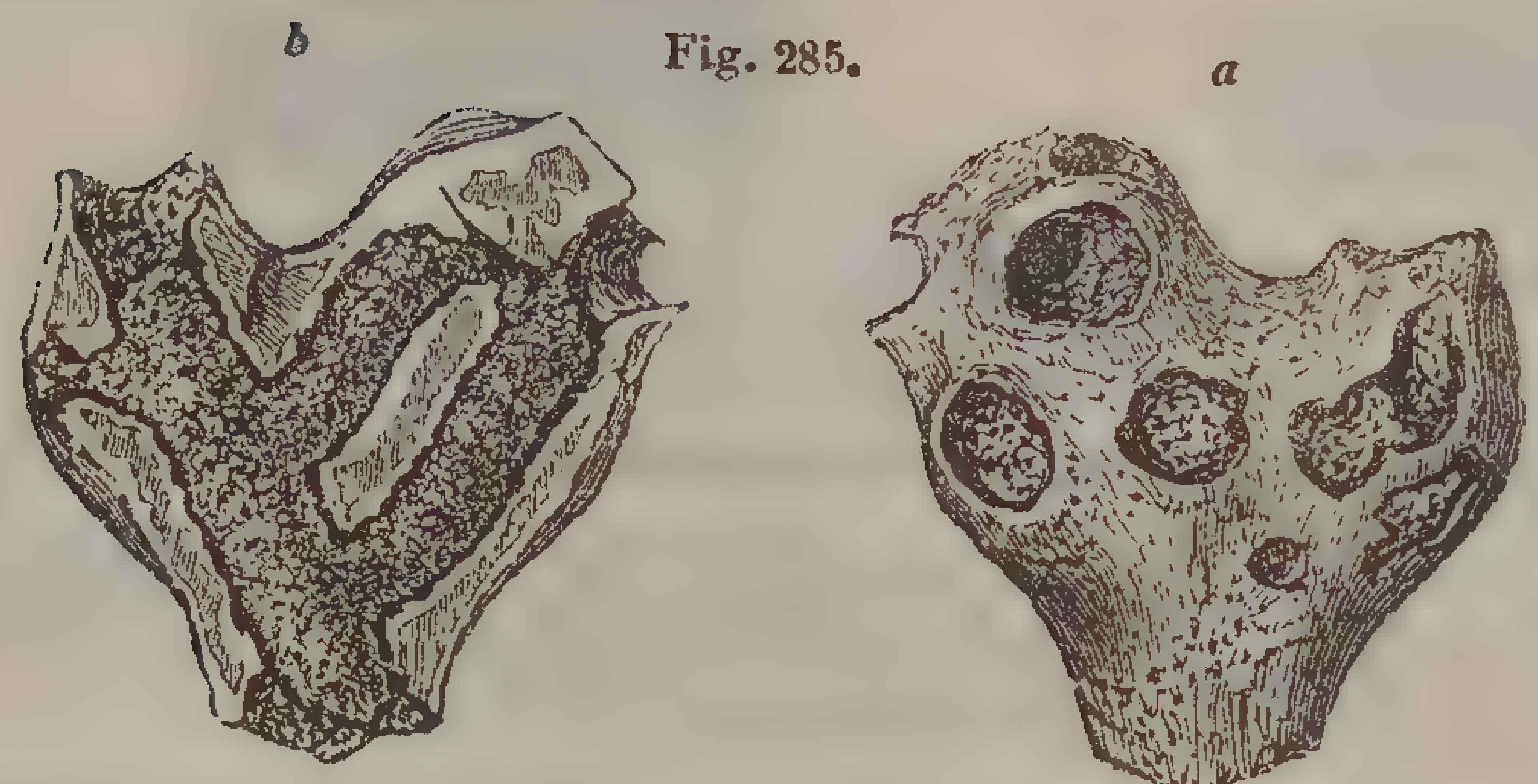
Escharina oceani.
a. Natural size.
b. Part of the same magnified. White chalk.

Fig. 284.

Ventriculites radiatus, Mantell.
Syn. *Ocellaria radiata*, D'Orb. White chalk.

and *Siphonia* (fig. 286.), are dispersed indifferently through the soft chalk and hard flint, and some of the flinty nodules owe their irregular forms to inclosed sponges, such as fig. 285. *a.*, where the hollows in the exterior are caused by the branches of a sponge, seen on breaking open the flint (fig. 285. *b.*).

Fig. 285.



A branching sponge in a flint, from the white chalk.
From the collection of Mr. Bowerbank.

Fig. 286.

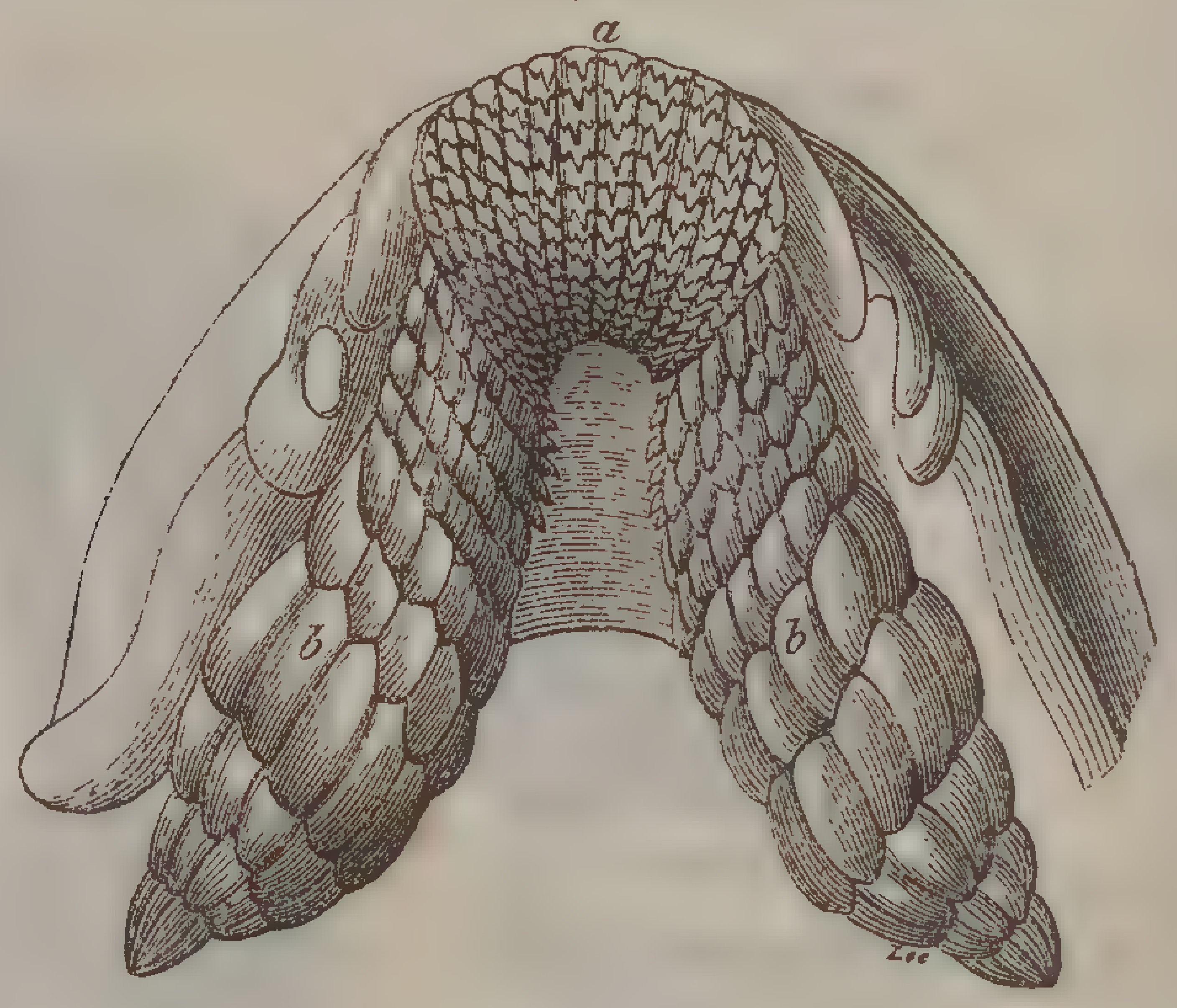
Siphonia pyriformis.
Chalk marl.

The remains of fishes of the Upper Cretaceous formations consist chiefly of teeth of the shark family of genera, in part common to the tertiary, and partly distinct. To the latter belongs the genus *Ptychodus* (fig. 287.), which is allied to the living Port Jackson

Fig. 287.

Palatal tooth of
Ptychodus decurrens.
Lower white chalk.
Maidstone.

Fig. 288.



Cestracion Phillippi; recent.
Port Jackson. Buckland, Bridgewater Treatise, pl. 27. *d.*

Shark, *Cestracion Phillippi*, the anterior teeth of which (see fig. 288. *a*) are sharp and cutting, while the posterior or palatal teeth (*b*) are flat, and analogous to the fossil (fig. 287.).

But we meet with no bones of land animals, nor any terrestrial or fluviatile shells, nor any plants, except sea-weeds, and here and there a piece of drift wood. All the appearances concur in leading us to conclude that the white chalk was the product of an open sea of considerable depth.

The existence of turtles and oviparous saurians, and of a Pterodactyl or winged-lizard, found in the white chalk of Maidstone, implies, no doubt, some neighbouring land; but a few small islets in mid-ocean, like Ascension, formerly so much frequented by migratory droves of turtle, might perhaps have afforded the required retreat where these creatures laid their eggs in the sand, or from which the flying species may have been blown out to sea. Of the vegetation of such islands we have scarcely any indication, but it consisted partly of cycadeous plants; for a fragment of one of these was found by Capt. Ibbetson in the chalk marl of the Isle of Wight, and is referred by A. Brongniart to *Clathraria Lyellii*, Mantell, a species common to the antecedent Wealden period.

The Pterodactyl of the Kentish chalk, above alluded to, was of gigantic dimensions, measuring 16 feet 6 inches from tip to tip of its outstretched wings. Some of its elongated bones were at first mistaken by able anatomists for those of birds; of which class no osseous remains seem as yet to have been derived from the chalk, or indeed from any secondary or primary formation, except perhaps the Wealden.

Upper greensand (Table, p. 105. &c.). — The lower chalk without flints passes gradually downwards, in the south of England, into an argillaceous limestone, "the chalk marl," already alluded to, in which ammonites and other cephalopoda, so rare in the higher parts of the series, appear. This marly deposit passes in its turn into beds called the Upper Greensand, containing green particles of sand of a chloritic mineral. In parts of Surrey, calcareous matter is largely intermixed, forming a stone called *firestone*. In the cliffs of the southern coast of the Isle of Wight, this upper greensand is 100 feet thick, and contains bands of siliceous limestone and calcareous sandstone with nodules of chert.

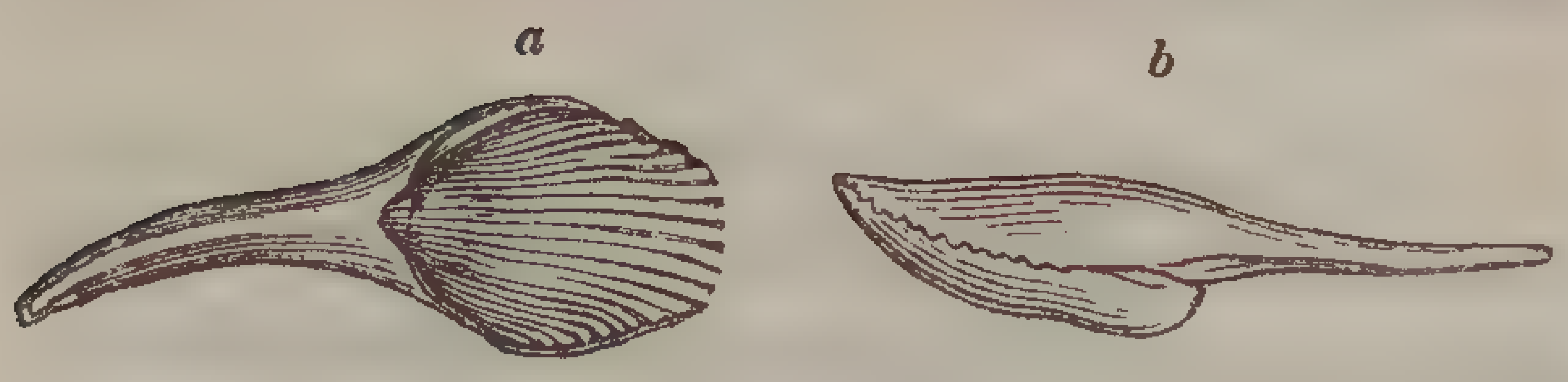
The Upper Greensand is regarded by Mr. Austen and Mr. D. Sharpe, as a littoral deposit of the Chalk Ocean, and, therefore, contemporaneous with part of the chalk marl, and even, perhaps, with some part of the white chalk. For as the land went on sinking, and the cretaceous sea widened its area, white mud and chloritic sand were always forming somewhere, but the line of sea-shore was perpetually varying its position. Hence, though both sand and mud originated simultaneously, the one near the land, the other far from it, the sands in every locality where a shore became submerged, might constitute the underlying deposit.

Gault. — The lowest member of the upper Cretaceous group, usually about 100 feet thick in the S.E. of England, is provincially termed

Gault. It consists of a dark blue marl, sometimes intermixed with greensand. Many peculiar forms of cephalopoda, such as the *Hamite* (fig. 291.) and *Scaphite*, with other fossils, characterize this formation, which, small as is its thickness, can be traced by its organic remains to distant parts of Europe, as, for example, to the Alps.

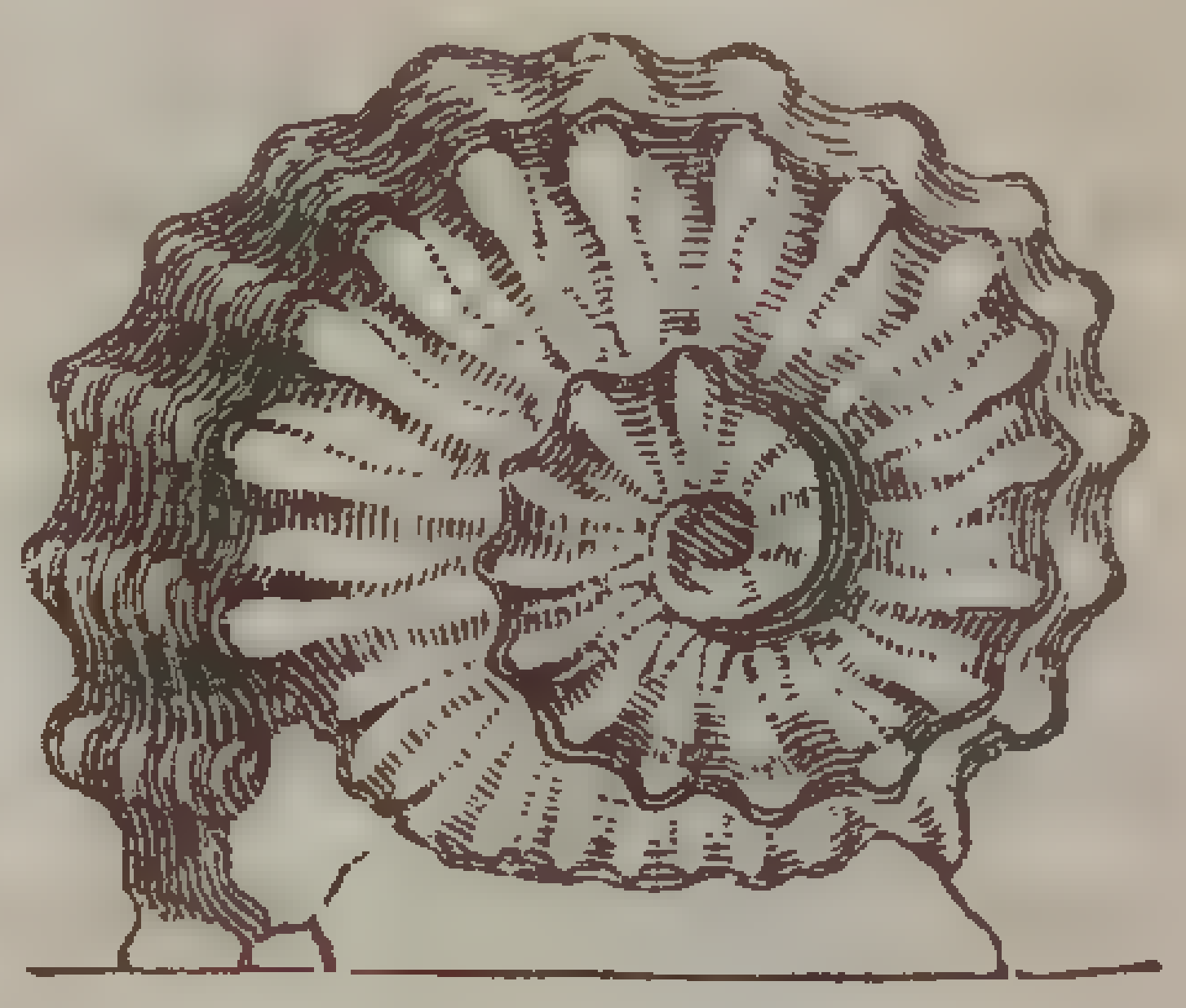
Fossils of the Upper Greensand.

Fig. 289.



a. Terebratula lyra.
b. Same, seen in profile. } Upper greensand. France.

Fig. 290.



Ammonites Rhotomagensis.
Upper greensand.

Fig. 291.

Hamites spiniger (Fitton); near Folkstone. Gault.

The Blackdown beds in Dorsetshire, celebrated for containing many species of fossils not found elsewhere, have been commonly referred to the Upper Greensand, which they resemble in mineral character; but Mr. Sharpe has suggested, and apparently with reason, that they are rather the equivalent of the Gault, and were probably formed on the shore of the sea, in the deeper parts of which the fine mud called Gault was deposited. Several Blackdown species are common to the Lower cretaceous series, as, for example, *Trigonia caudata*, fig. 299. We learn from M. D'Archiac, that in France, at Mons, in the valley of the Loire, strata of greensand occur of the same age as the Blackdown beds, and containing many of the same fossils. They are also regarded as of littoral origin by M. D'Archiac.*

The phosphate of lime, found near Farnham, in Surrey, in such abundance as to be used largely by the agriculturist for fertilizing soils, occurs exclusively, according to Mr. R. A. C. Austen, in the upper greensand and gault. It is doubtless of animal origin, and partly coprolitic, probably derived from the excrement of fish.

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* Hist. des Progrès de la Géol., &c., vol. iv. p. 360., 1851.

HIPPURITE LIMESTONE.

Difference between the chalk of the north and south of Europe. — By the aid of the three tests of relative age, namely, superposition, mineral character, and fossils, the geologist has been enabled to refer to the same Cretaceous period certain rocks in the north and south of Europe, which differ greatly, both in their fossil contents and in their mineral composition and structure.

If we attempt to trace the cretaceous deposits from England and France to the countries bordering the Mediterranean, we perceive, in the first place, that the chalk and greensand in the neighbourhood of London and Paris form one great continuous mass, the Straits of Dover being a trifling interruption, a mere valley with chalk cliffs on both sides. We then observe that the main body of the chalk which surrounds Paris stretches from Tours to near Poitiers (see the annexed map, fig. 292., in which the shaded part represents chalk).

Fig. 292.

Between Poitiers and La Rochelle, the space marked A on the map separates two regions of chalk. This space is occupied by the Oolite and certain other formations older than the Chalk, and has been supposed by M. E. de Beaumont to have formed an island in the cretaceous sea. South of this space we again meet with a formation which we at once recognize by its mineral character to be chalk, although there are some places where the rock becomes oolitic. The fossils are, upon the whole, very similar; especially certain species of the genera *Spatangus, Ananchytes, Cidarites, Nucula, Ostrea, Gryphæa* (*Exogyra*), *Pecten, Plagiostoma* (*Lima*), *Trigonia, Catillus* (*Inoceramus*), and *Terebratula.** But *Ammonites*, as M. d'Archiac observes, of which so many species are met with in the chalk of the north of France, are scarcely ever found in the southern region; while the genera *Hamite, Turrilite,* and *Scaphite,* and perhaps *Belemnite,* are entirely wanting.

On the other hand, certain forms are common in the south which are rare or wholly unknown in the north of France. Among these may be mentioned many *Hippurites, Sphærulites,* and other members of that great family of mollusca called *Rudistes* by Lamarck, to which nothing analogous has been discovered in the living creation, but which is quite characteristic of rocks of the Cretaceous era in

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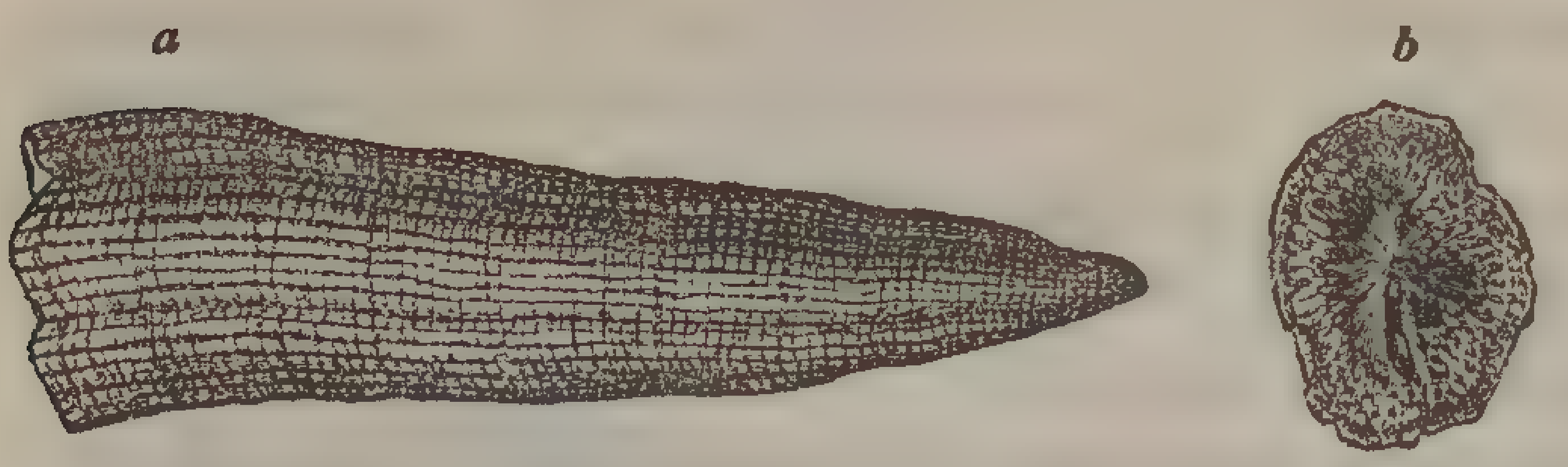
* D'Archiac, sur la Form. Crétacée du S. O. de la France, Mém. de la Soc. Géol. de France, tom. ii.

the south of France, Spain, Sicily, Greece, and other countries bordering the Mediterranean.

Fig. 293.

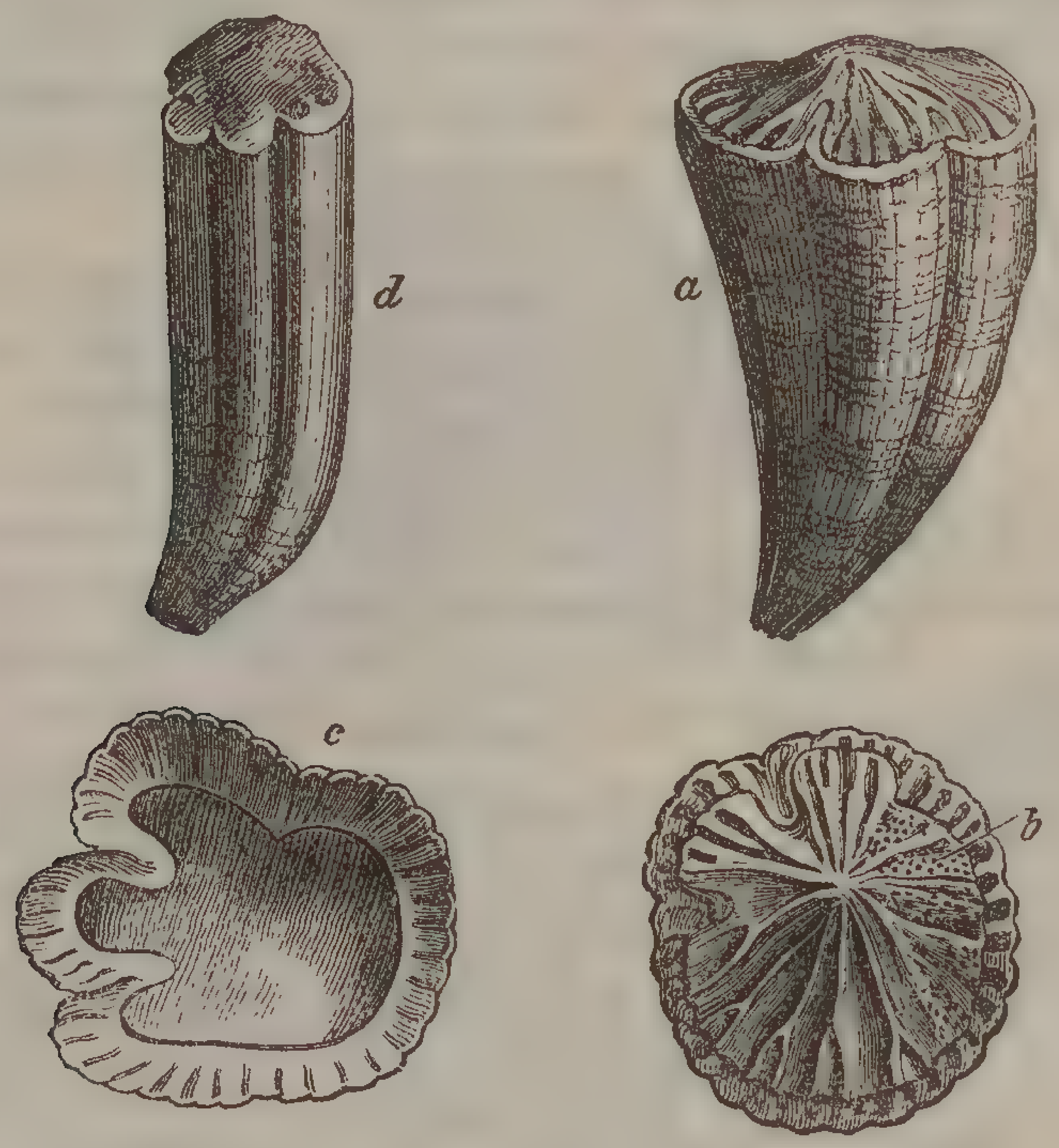


a. Radiolites radiosus, D'Orb. (*Hippurites*, Lam.)
b. Upper valve of same.
White chalk of France.

Fig. 294.

Radiolites foliaceus, D'Orb.
Syn. *Sphærulites agariciformis*, Blainv.
White chalk of France.

Fig. 295.



Hippurites organisans, Desmoulins,
Upper chalk: — chalk marl of Pyrenees ?*
a. Young individual; when full grown they occur in groups adhering laterally to each other.
b. Upper side of the upper valve, showing a reticulated structure in those parts, *b*, where the external coating is worn off.
c. Upper end or opening of the lower and cylindrical valve
d. Cast of the interior of the lower conical valve.

The species called *Hippurites organisans* (fig. 295.) is more abundant than any other in the south of Europe; and the geologist should make himself well acquainted with the cast *d*, which is far more common in many compact marbles of the upper cretaceous period than the shell itself, this having often wholly disappeared. The flutings, or smooth, rounded, longitudinal ribs, representing the form of the interior, are wholly unlike the Hippurite itself, and in some individuals attain a great size and length.

Between the region of chalk last mentioned, in which Perigueux is situated, and the Pyrenees, the space B intervenes. (See Map,

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* D'Orbigny's Paléontologie Française, pl. 533.

fig. 292.). Here the tertiary strata cover, and for the most part conceal, the cretaceous rocks, except in some spots where they have been laid open by the denudation of the newer formations. In these places they are seen still preserving the form of a white chalky rock, which is charged in part with grains of greensand. Even as far south as Tercis, on the Adour, near Dax, cretaceous rocks retain this character where I examined them in 1828, and where M. Grateloup has found in them *Ananchytes ovata* (fig. 253.), and other fossils of the English chalk, together with *Hippurites.*

CRETACEOUS ROCKS IN THE UNITED STATES.

If we pass to the American continent, we find in the state of New Jersey a series of sandy and argillaceous beds wholly unlike our Upper Cretaceous system; which we can, nevertheless, recognize as referable, paleontologically, to the same division.

That they were about the same age generally as the European chalk and greensand, was the conclusion to which Dr. Morton and Mr. Conrad came after their investigation of the fossils in 1834. The strata consist chiefly of greensand and green marl, with an overlying coralline limestone of a pale yellow colour, and the fossils, on the whole, agree most nearly with those of the upper European series, from the Maestricht beds to the gault inclusive. I collected sixty shells from the New Jersey deposits in 1841, five of which were identical with European species — *Ostrea larva, O. vesicularis, Gryphæa costata, Pecten quinque-costatus, Belemnites mucronatus.* As some of these have the greatest vertical range in Europe, they might be expected more than any others to recur in distant parts of the globe. Even where the species are different, the generic forms, such as the Baculite and certain sections of Ammonites, as also the *Inoceramus* (see above, fig. 274.) and other bivalves, have a decidedly cretaceous aspect. Fifteen out of the sixty shells above alluded to were regarded by Professor Forbes as good geographical representatives of well-known cretaceous fossils of Europe. The correspondence, therefore, is not small, when we reflect that the part of the United States where these strata occur is between 3000 and 4000 miles distant from the chalk of Central and Northern Europe, and that there is a difference of ten degrees in the latitude of the places compared on opposite sides of the Atlantic.*

Fish of the genera *Lamna, Galeus,* and *Carcharodon* are common to New Jersey and the European cretaceous rocks. So also is the genus *Mosasaurus* among reptiles. The vertebra of a Plesiosaurus, a reptile known in the English chalk, had often been cited on the authority of Dr. Harlan as occurring in the cretaceous marl, at Mullica Hill, in New Jersey. But Dr. Leidy has since shown that the bone in question is not saurian but cetaceous, and whether it can truly lay claim to the high antiquity assigned to it, is a point still open to discussion. The discovery of another mammal of the seal

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* See a paper by the author, Quart. Journ. Geol. Soc. vol. i. p. 79.

tribe (*Stenorhynchus vetus*, Leidy), from a lower bed in the cretaceous series in New Jersey, appears to rest on better evidence.*

From New Jersey the cretaceous formation extends southwards to North Carolina and Georgia, cropping out at intervals from beneath the tertiary strata, between the Appalachian Mountains and the Atlantic. They then sweep round the southern extremity of that chain, in Alabama and Mississippi, and stretch northwards again to Tennessee and Kentucky. They have also been traced far up the valley of the Missouri, as far north as lat. 48°, or to Fort Mandan; so that already the area which they are ascertained to occupy in North America may perhaps equal their extent in Europe, and exceeds that of any other fossiliferous formation in the United States. So little do they resemble mineralogically the European white chalk, that in North America, limestone is upon the whole, an exception to the rule; and, even in Alabama, where I saw a calcareous member of this group, composed of marl-stone, it was more like the English and French Lias than any other European secondary deposit.

At the base of the system in Alabama, I found dense masses of shingle, perfectly loose and unconsolidated, derived from the waste of paleozoic (or carboniferous) rocks, a mass in no way distinguishable, except by its position, from ordinary alluvium, but covered with marls abounding in Inocerami.

In Texas, according to F. Römer, the chalk assumes a new lithological type, a large portion of it consisting of hard siliceous limestone, but the organic remains leave no doubt in regard to its age, the *Baculites anceps* and ten other European species occurring there.

In South America the cretaceous strata have been discovered in Columbia, as at Bogota and elsewhere, containing Ammonites, Hamites, Inocerami, and other characteristic shells.†

In the South of India, also, at Pondicherry, Verdachellum, and Trinconopoly, Messrs. Kaye and Egerton have collected fossils belonging to the cretaceous system. Taken in connection with those from the United States, they prove, says Prof. E. Forbes, that those powerful causes which stamped a peculiar character on the forms of

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* In the Principles of Geology, ninth ed. p. 145., I cited Dr. Leidy of Philadelphia as having described (Proceedings of Acad. Nat. Sci. Philad., 1851) two species of cetacea of a new genus which he called *Priscodelphinus*, from the greensand of New Jersey. In 1853, I saw the two vertebræ at Philadelphia on which this new genus was founded, and afterwards, with the aid of Mr. Conrad, traced one of them to a *Miocene* marl pit in Cumberland county New Jersey. The other (the Plesiosaurus of Harlan), labelled "Mullica Hill" in the Museum, would no doubt be an upper cretaceous fossil, if really derived from that locality, but its mineral condition makes the point rather doubtful. The tooth of *Stenorhynchus vetus*, figured by Leidy from a drawing of Conrad's (Proceed. of Acad. Nat. Sci. Philad. 1853, p. 377.), was found by Samuel R. Wetherill, Esq., in the greensand $1\frac{1}{2}$ miles south-east of Burlington. This gentleman related to me and Mr. Conrad, in 1853, the circumstances under which he met with it, associated with *Ammonites placenta*, *Ammonites Delawarensis*, *Trigonia thoracica*, &c. The tooth has been mislaid, but not until it had excited much interest and had been carefully examined by good zoologists.

† Proceedings of the Geol. Soc. vol. iv. p. 391.

marine animal life at this period, exerted their full intensity through the Indian, European, and American seas.* Here, as in North and South America, the cretaceous character can be recognized even where there is no specific identity in the fossils; and the same may be said of the organic type of those rocks in Europe and India which occur next to the chalk in the ascending and descending order, namely the Eocene and the Oolitic.

CHAPTER XVIII.

LOWER CRETACEOUS AND WEALDEN FORMATIONS.

Lower Greensand — Term "Neocomian" — Atherfield section, Isle of Wight — Fossils of Lower Greensand — Wealden Formation — Freshwater strata intercalated between two marine groups — Weald Clay and Hastings Sand — Fossil shells, fish, and plants of Wealden — Their relation to the Cretaceous type — Geographical extent of Wealden — Movements in the earth's crust to which the Wealden owed its origin and submergence — Flora of the Lower Cretaceous and Wealden Periods.

THE term "Lower Greensand" has hitherto been most commonly applied to such portions of the Cretaceous series as are older than the Gault. But the name has often been complained of as inconvenient, and not without reason, since green particles are wanting in a large part of the strata so designated, even in England, and wholly so in some European countries. Moreover, a subdivision of the Upper Cretaceous group has likewise been called Greensand, and to prevent confusion the terms Upper and Lower Greensand were introduced. Such a nomenclature naturally leads the uninitiated to suppose that the two formations so named are of somewhat co-ordinate value, which is so far from being true, that the Lower Greensand, in its widest acceptation, embraces a series nearly as important as the whole Upper Cretaceous group, from the Gault to the Maestricht beds inclusive; while the Upper Greensand is but one subordinate member of this same group. Many eminent geologists have, therefore, proposed the term "Neocomian" as a substitute for Lower Greensand; because, near Neufchatel (Neocomum), in Switzerland, these Lower Greensand strata are well developed, entering largely into the structure of the Jura mountains. By the same geologists the Wealden beds are usually classed as "Lower Neocomian," a classification which will not appear inappropriate when we have explained, in the sequel, the intimate relation of the Lower Greensand and Wealden fossils.

Dr. Fitton, to whom we are indebted for an excellent monograph on the Lower Cretaceous (or Greensand) formation as developed in

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* See Forbes, Quart. Geol. Journ. vol. i. p. 79.

England, gives the following as the succession of rocks seen in parts of Kent.

No. 1.	Sand, white, yellowish, or ferruginous, with concretions of limestone and chert - - - -	70 feet.
2.	Sand with green matter - - - - -	70 to 100 feet.
3.	Calcareous stone, called Kentish rag - - -	60 to 80 feet.

In his detailed description of the fine section displayed at Atherfield, in the south of the Isle of Wight, we find the limestone wholly wanting; in fact, the variations in the mineral composition of this group, even in contiguous districts, is very great; and on comparing the Atherfield beds with corresponding strata at Hythe in Kent, distant 95 miles, the whole series presents a most dissimilar aspect.*

On the other hand, Professor E. Forbes has shown that when the sixty-three strata at Atherfield are severally examined, the total thickness of which he gives as 843 feet, there are some fossils which range through the whole series, others which are peculiar to particular divisions. As a proof that all belong chronologically to one system, he states that whenever similar conditions are repeated in overlying strata the same species reappear. Changes of depth, or of the mineral nature of the sea-bottom, the presence or absence of lime or of peroxide of iron, the occurrence of a muddy, or a sandy, or a gravelly bottom, are marked by the banishment of certain species and the predominance of others. But these differences of conditions being mineral, chemical, and local in their nature, have nothing to do with the extinction, throughout a large area, of certain animals or plants. The rule laid down by this eminent naturalist for enabling us to test the arrival of a new state of things in the animate world, is the representation by new and different species of corresponding genera of mollusca or other beings. When the forms proper to loose sand or soft clay, or a stony or calcareous bottom, or a moderate or a great depth of water, recur with all the same species, the interval of time has been, geologically speaking, small, however dense the mass of matter accumulated. But if, the genera remaining the same, the species are changed, we have entered upon a new period; and no similarity of climate, or of geographical and local conditions, can then recall the old species which a long series of destructive causes in the animate and inanimate world has gradually annihilated. On passing from the Lower Greensand to the Gault, we suddenly reach one of these new epochs, scarcely any of the fossil species being common to the lower and upper cretaceous systems, a break in the chain implying no doubt many missing links in the series of geological monuments, which we may some day be able to supply.

One of the largest and most abundant shells in the lowest strata of the Lower Greensand, as displayed in the Atherfield section, is

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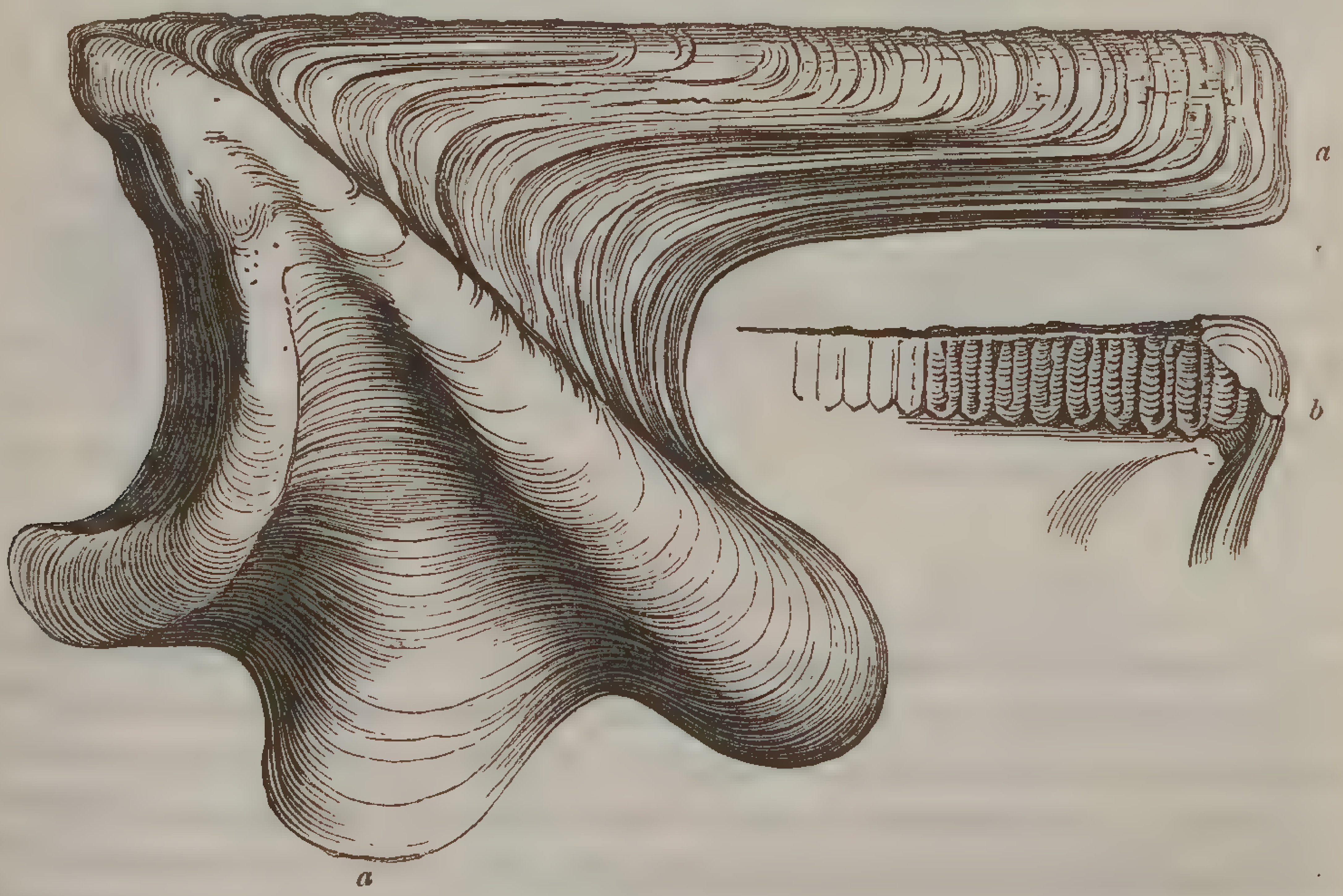
* Dr. Fitton, Quart. Geol. Journ., vol. i. p. 179., ii. p. 55., and iii. p. 289., where comparative sections and a valuable table showing the vertical range of the various fossils of the lower greensand at Atherfield are given.

the large *Perna Mulleti*, of which a reduced figure is here given (fig. 296.).

Fig. 296.



Perna Mulleti. Desh. in Leym.
a. Exterior. *b*. Part of hinge of upper valve.

In the south of England, during the accumulation of the Lower Greensand above described, the bed of the sea appears to have been continually sinking, from the commencement of the period, when the freshwater Wealden beds were submerged, to the deposition of those strata on which the gault immediately reposes.

Pebbles of quartzose sandstone, jasper, and flinty slate, together with grains of chlorite and mica, speak plainly of the nature of the pre-existing rocks, from the wearing down of which the Greensand beds were derived. The land, consisting of such rocks, was doubtless submerged before the origin of the white chalk, a deposit which originated in a more open sea, and in clearer waters.

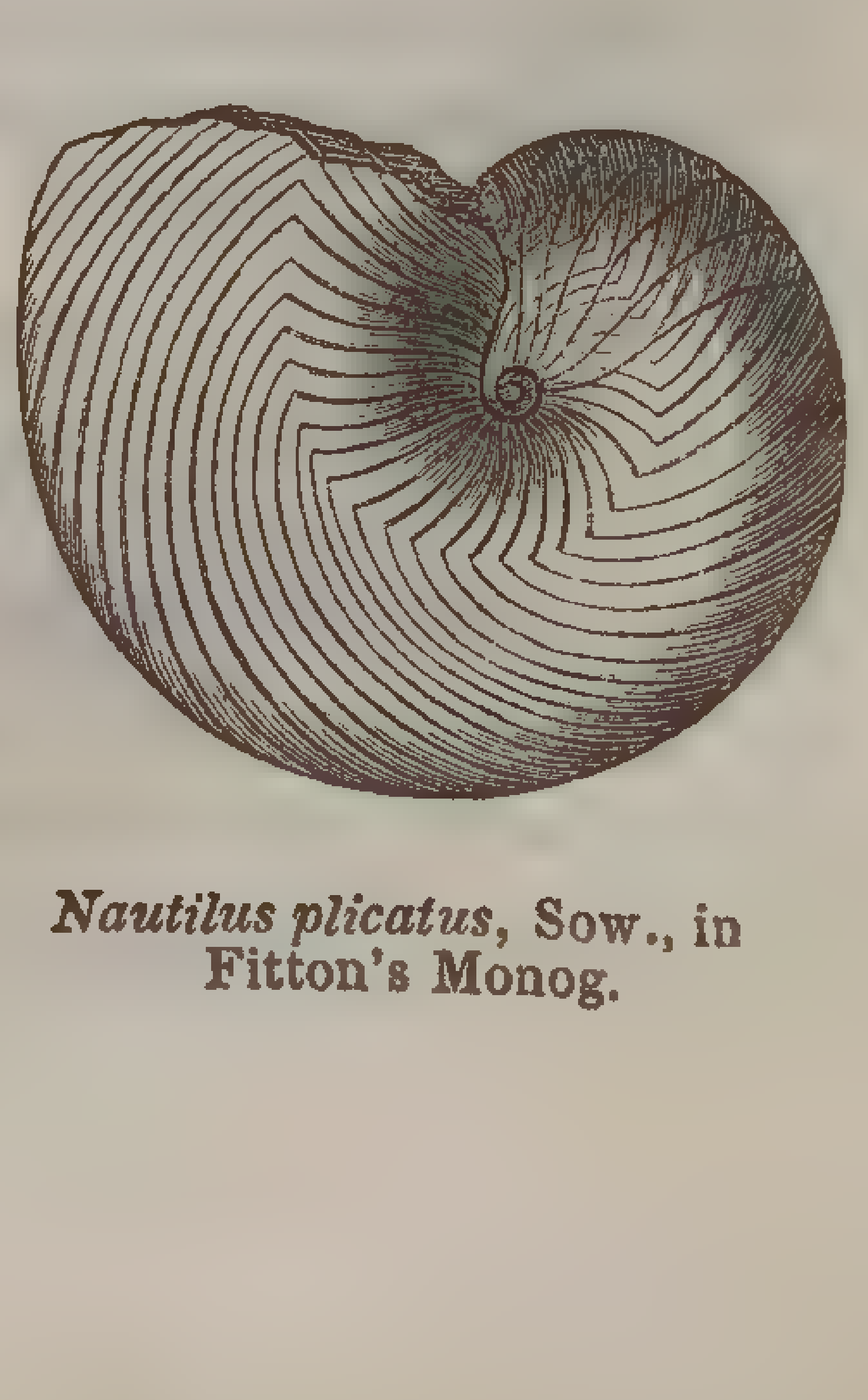
The fossils of the Lower Cretaceous are for the most part specifically distinct from those of the Upper Cretaceous strata.

Among the former we often meet with the genus *Scaphites* (fig. 297.)

Fig. 297.

Scaphites gigas, Sow. Syn. *Ancyloceras gigas*, D'Orb.

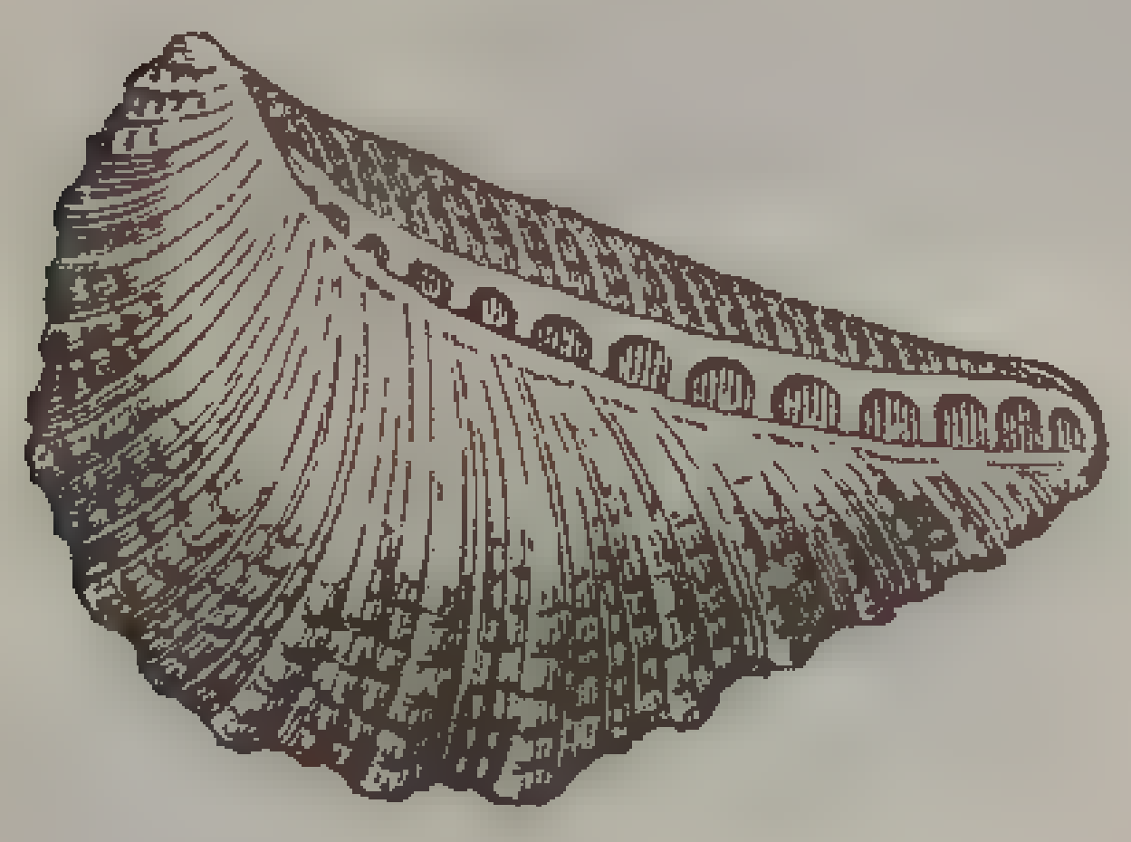
Fig. 298.



Nautilus plicatus, Sow., in Fitton's Monog.

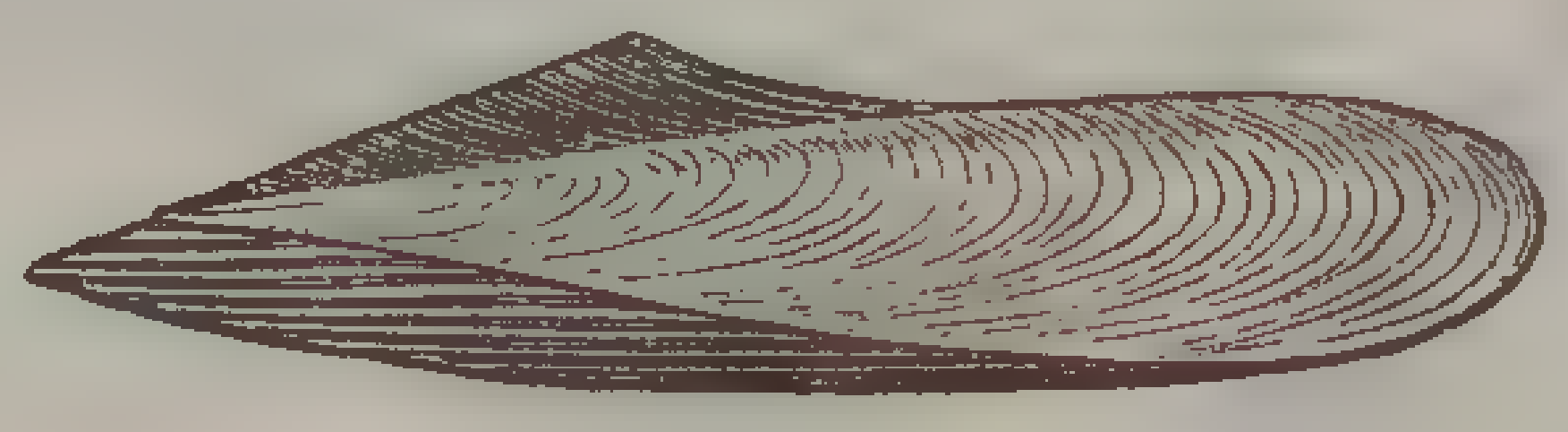
or *Ancyloceras,* which has been aptly described as an ammonite more or less uncoiled; also a furrowed *Nautilus, N. plicatus* (fig. 298.), *Trigonia caudata,* likewise found in the Blackdown beds (see above, p. 252.), and *Gervillia,* a bivalve genus allied to *Avicula.*

Fig. 299.



Trigonia caudata, Agass.

Fig. 300.



Gervillia anceps, Desh.

Fig. 301.

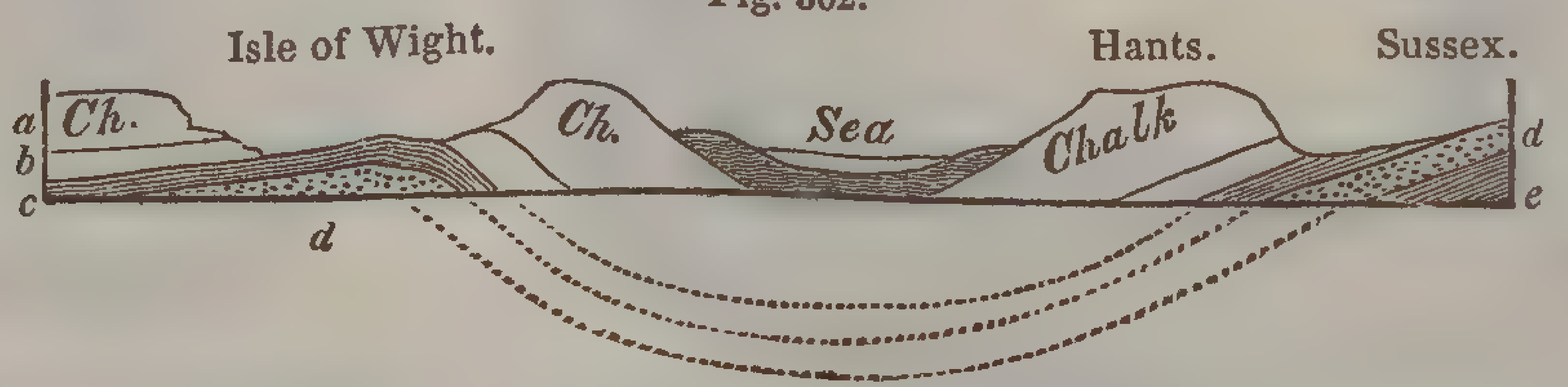
Terebratula tella, Sow

WEALDEN FORMATION.

Beneath the Lower Greensand in the S. E. of England, a freshwater formation is found, called the Wealden (see Nos. 5 and 6. Map, fig. 320. p. 273.), which, although it occupies a small horizontal area in Europe, as compared to the White Chalk and Greensand, is nevertheless of great geological interest, since the imbedded remains give us some insight into the nature of the terrestrial fauna and flora of the Lower Cretaceous epoch. The name of Wealden was given to this group because it was first studied in parts of Kent, Surrey, and Sussex, called the Weald (see Map, p. 273.); and we are indebted to Dr. Mantell for having shown, in 1822, in his Geology of Sussex, that the whole group was of fluviatile origin. In proof of this he called attention to the entire absence of Ammonites, Belemnites, Terebratulæ, Echinites, Corals, and other marine fossils, so characteristic of the cretaceous rocks above, and of the Oolitic strata below, and to the presence in the Weald of Paludinæ, Melaniæ, and various fluviatile shells, as well as the bones of terrestrial reptiles and the trunks and leaves of land plants.

The evidence of so unexpected a fact as the infra-position of a dense mass of purely freshwater origin to a deep-sea deposit (a phenomenon with which we have since become familiar) was received, at first, with no small doubt and incredulity. But the relative position of the beds is unequivocal; the Weald Clay being distinctly seen to pass beneath the Lower Greensand in various parts of Surrey, Kent, and Sussex, and to re-appear in the Isle of Wight at the base of the Cretaceous Series, being, no doubt, continuous far beneath the surface, as indicated by the dotted lines in the annexed diagram, fig. 302.

Fig. 302.



a. Chalk. *b.* Greensand. *c.* Weald Clay. *d.* Hastings Sand. *e.* Purbeck beds.

The Wealden is divisible into two minor groups:—

		Thickness.
1st.	Weald Clay, chiefly argillaceous, but sometimes including thin beds of sand and shelly limestone with *Paludina*	140 to 280 ft.
2d.	Hastings Sand, chiefly arenaceous, but in which occur some clays and calcareous grits* - - -	400 to 1000 ft.

Another freshwater formation, called the Purbeck, consisting of various limestones and marls, containing distinct species of molluscs, *Cyprides*, and other fossils, lies immediately beneath the Wealden in the south-east of England. As it is now found to be more nearly related, by its organic remains, to the Oolitic than to the Cretaceous Series, it will be treated of in the 20th Chapter.

Weald Clay.

The upper division, or Weald Clay, is of purely freshwater origin. Its highest beds are not only conformable, as Dr. Fitton observes, to the inferior strata of the Lower Greensand, but of similar mineral composition. To explain this, we may suppose, that, as the delta of a great river was tranquilly subsiding, so as to allow the sea to encroach upon the space previously occupied by fresh water, the river still continued to carry down the same sediment into the sea. In confirmation of this view it may be stated, that the remains of the *Iguanodon Mantelli*, a gigantic terrestrial reptile, very characteristic of the Wealden, has been discovered near Maidstone, in the overlying Kentish rag, or marine limestone of the Lower Greensand. Hence we may infer, that some of the saurians which inhabited the country of the great river continued to live when part of the country had become submerged beneath the sea. Thus, in our own times, we may suppose the bones of large alligators to be frequently entombed in recent freshwater strata in the delta of the Ganges. But if part of that delta should sink down so as to be covered by the sea, marine formations might begin to accumulate in the same space where freshwater beds had previously been formed; and yet the Ganges might still pour down its turbid waters in the same direction, and carry seaward the carcases of the same species of alligator, in which case their bones might be included in marine as well as in subjacent freshwater strata.

The Iguanodon, first discovered by Dr. Mantell, has left more of its remains in the Wealden strata of the south-eastern counties and Isle of Wight than has any other genus of associated saurians. It was an herbivorous reptile, and regarded by Cuvier as more extraordinary than any with which he was acquainted; for the teeth, though bearing a great analogy, in their general form and crenated edges (see figs. 303. *a.*, 303. *b.*), to the modern Iguanas which now frequent the tropical woods of America and the West Indies, exhibit many striking and important differences. It appears that they have often been worn by the process of mastication; whereas the

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* Dr. Fitton, Geol. Trans. Second Series, vol. iv. p. 320.

existing herbivorous reptiles clip and gnaw off the vegetable productions on which they feed, but do not chew them. Their teeth frequently present an appearance of having been chipped off, but never, like the fossil teeth of the Iguanodon, have a flat ground surface (see fig. 304. *b.*), resembling the grinders of herbivorous mammalia. Dr. Mantell computes that the teeth and bones of this species which passed under his examination during twenty years must have belonged to no less than seventy-one distinct individuals, varying in age and magnitude from the reptile just burst from the egg, to one of which the femur measured 24 inches in circumference. Yet, notwithstanding that the teeth were more numerous than any other bones, it is remarkable that it was not until the relics of all these individuals had been found, that a solitary example of part of a jaw-bone was obtained. More recently remains both of the upper and lower jaw have been met with in the Hastings Beds in Tilgate Forest. Their size was somewhat greater than had been anticipated, and Dr. Mantell, who does not agree with Professor Owen that the tail was short, estimates the probable length of some of these saurians at between 50 and 60 feet. The largest femur yet found measures 4 feet 8 inches in length, the circumference of the shaft being 25 inches, and, if measured round the condyles, 42 inches.

Fig. 303.

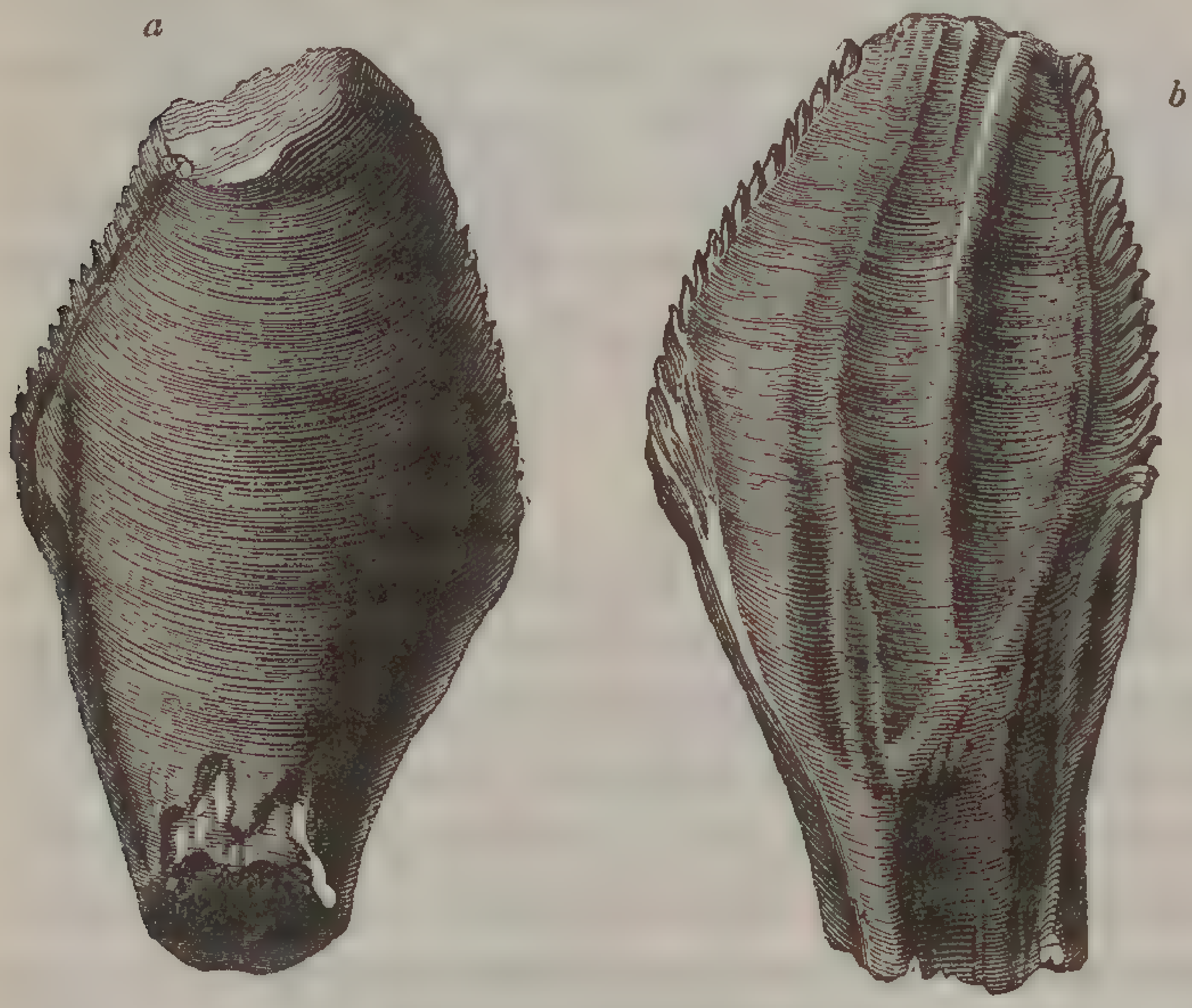


Fig. 304.

Fig. 303. *a*, *b*. Tooth of *Iguanodon Mantelli*.
Fig. 304. *a*. Partially worn tooth of young individual of the same.
b. Crown of tooth in adult, worn down. (Mantell.)

Occasionally bands of limestone, called Sussex Marble, occur in the Weald Clay, almost entirely composed of a species of *Paludina*, closely resembling the common *P. vivipara* of English rivers.

Shells of the *Cypris*, a genus of Crustaceans before mentioned (p. 31.) as abounding in lakes and ponds, are also plentifully scattered through the clays of the Wealden, sometimes producing, like plates of mica, a thin lamination (see fig. 307.). Similar cypris-bearing marls are found in the lacustrine tertiary beds of Auvergne (see above, p. 200.).

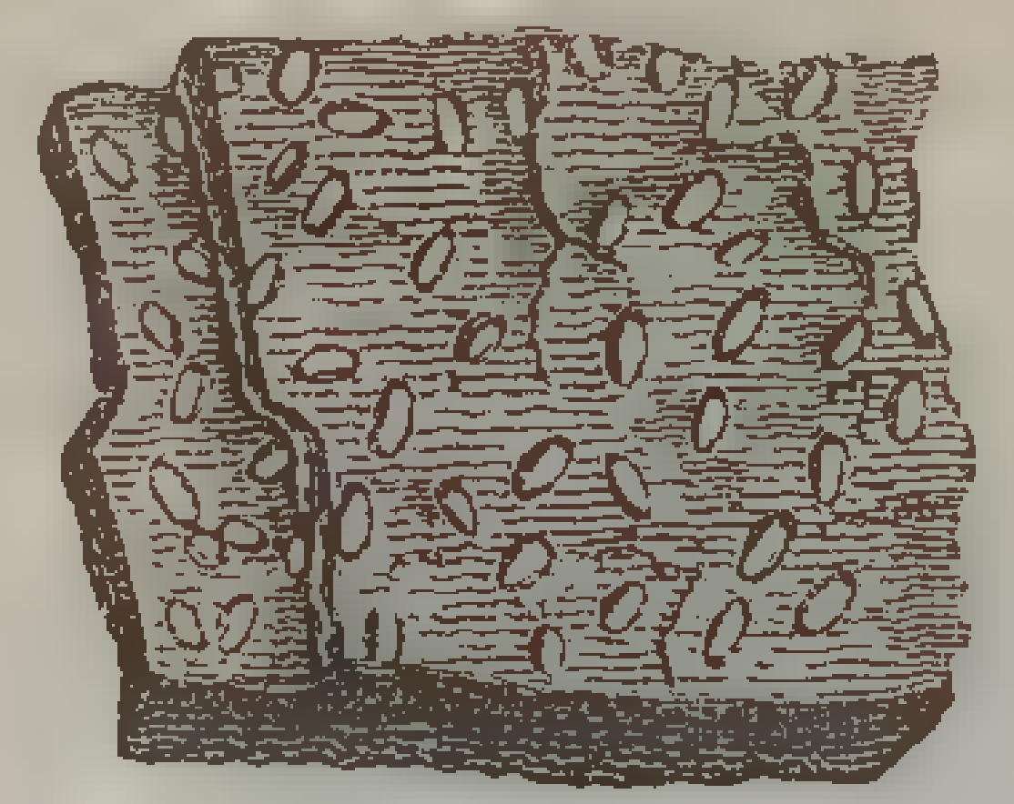
Fig. 305.

Cypris spinigera, Fitton.

Fig. 306.

Cypris Valdensis, Fitton.
(*C. faba*, Min. Con. 485.)

Fig. 307.



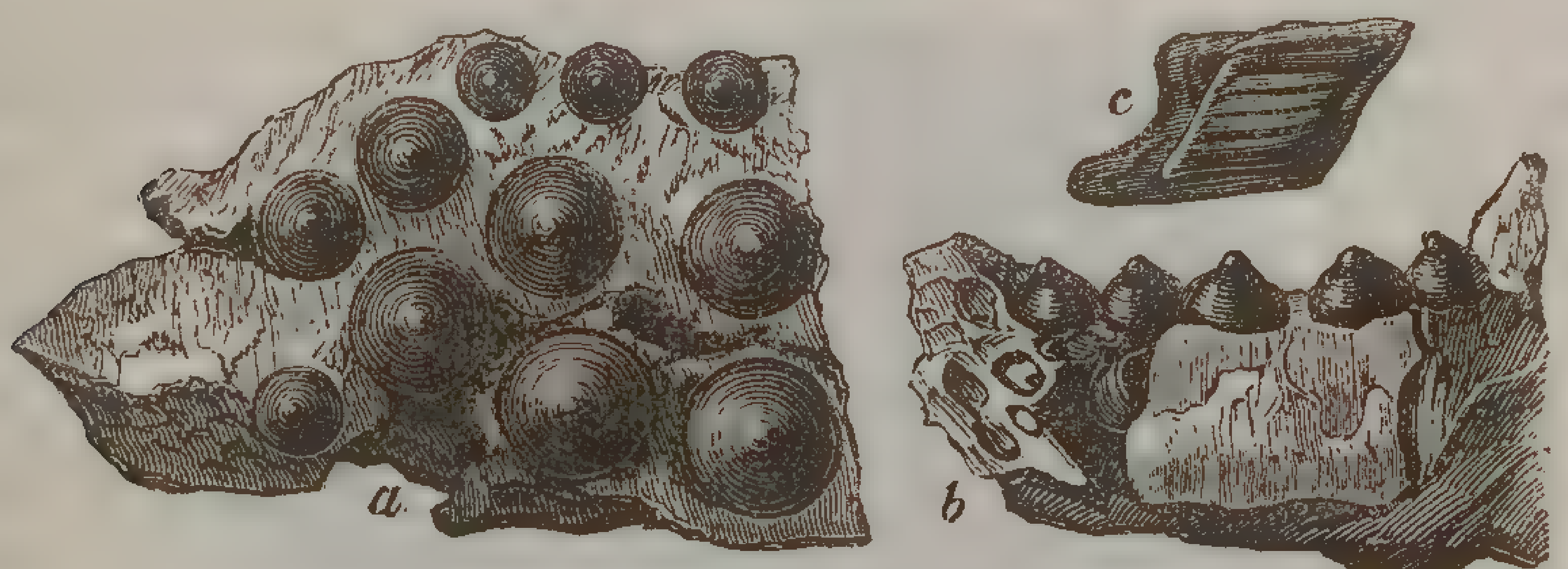
Weald clay with Cyprides.

Hastings Sands.

This lower division of the Wealden consists of sand, calciferous grit, clay, and shale; the argillaceous strata, notwithstanding the name, being nearly in the same proportion as the arenaceous. The calcareous sandstone and grit of Tilgate Forest, near Cuckfield, in which the remains of the Iguanodon and Hylæosaurus were first found, constitute an upper member of this formation. The white "sand-rock" of the Hastings cliffs, about 100 feet thick, is one of the lower members of the same. The reptiles, which are very abundant in this division, consist partly of saurians, already referred by Owen and Mantell to eight genera, among which, besides those already enumerated, we find the Megalosaurus and Plesiosaurus. The Pterodactyl also, a flying reptile, is met with in the same strata, and many remains of Chelonians of the genera *Trioynx* and *Emys*, now confined to tropical regions.

The fishes of the Wealden are chiefly referable to the Ganoid and Placoid orders. Among them the teeth and scales of *Lepidotus* are most widely diffused (see fig. 308.). These ganoids were allied to the *Lepidosteus*, or Gar-pike, of the American rivers. The whole body was covered with large rhomboidal scales, very thick, and having the exposed part coated with enamel. Most of the species of this genus are supposed to have been either river-fish, or inhabitants of the sea at the mouth of estuaries.

Fig. 308.



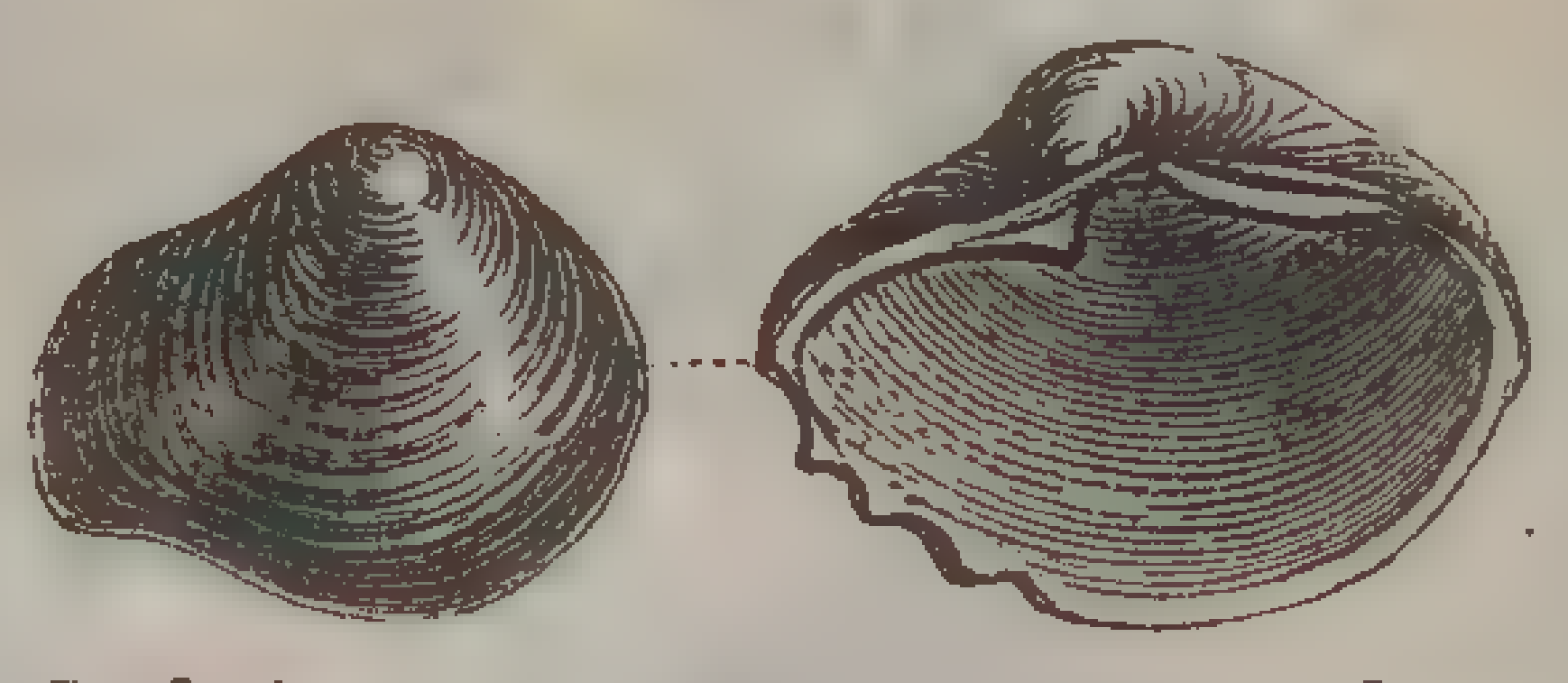
Lepidotus Mantelli, Agass. Wealden.
a. palate and teeth. *b.* side view of teeth. *c.* scale.

The shells of the Hastings beds belong to the genera *Melanopsis*, *Melania*, *Paludina*, *Cyrena*, *Cyclas*, *Unio* (see fig. 309.), and others, which inhabit rivers or lakes; but one band has been found at Punfield, in Dorsetshire, indicating a brackish state of the water, where the genera *Corbula* (see fig. 310.), *Mytilus*, and *Ostrea* occur;

Fig. 309.

Unio Valdensis, Mant.
Isle of Wight and Dorsetshire; in the lower beds of the Hastings Sands.

Fig. 310.

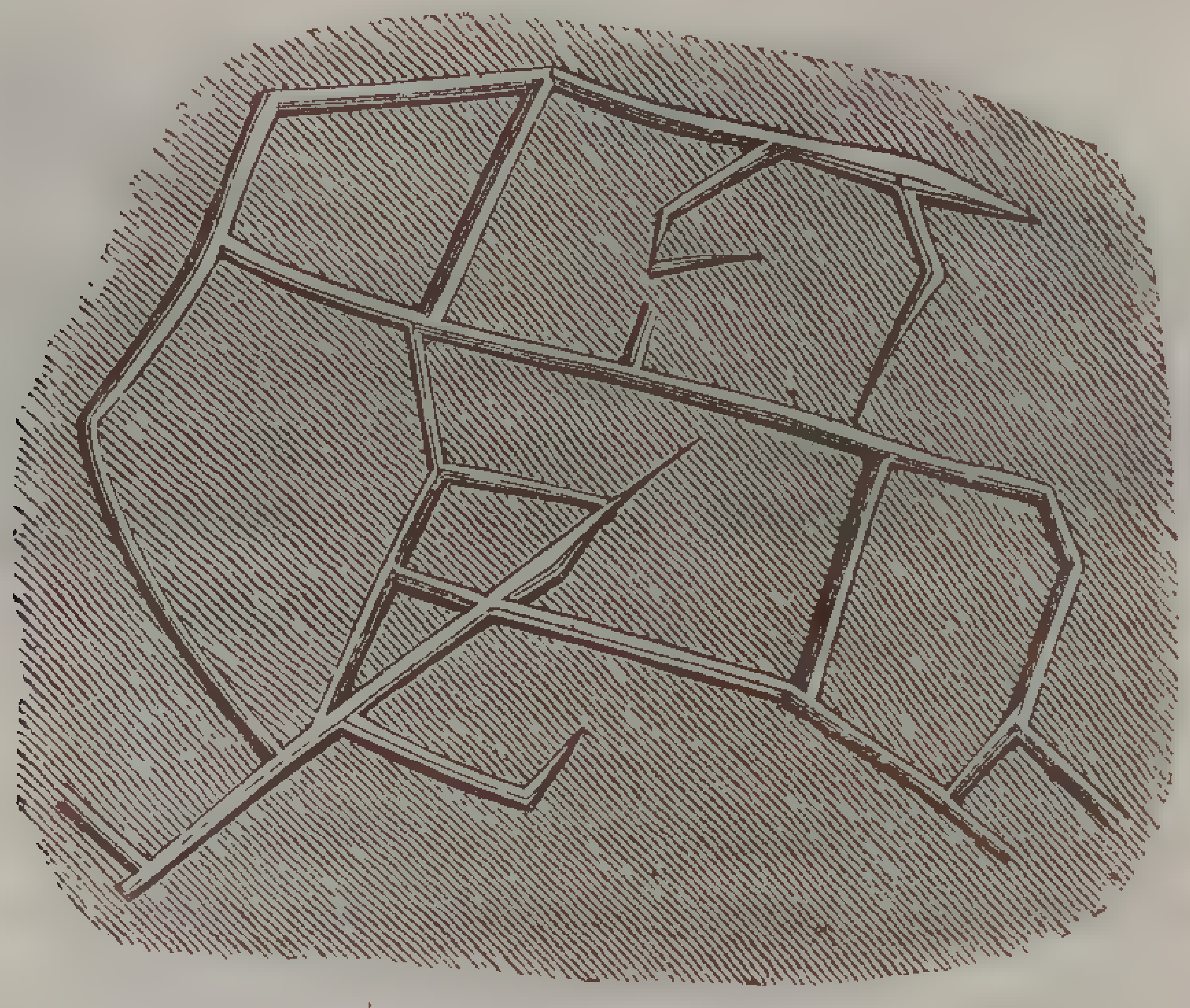


Corbula alata, Fitton. Magnified.
In brackish-water beds of the Hastings Sands, Punfield Bay.

and in some places this bed becomes purely marine, the species being for the most part peculiar, but several of them well-known Lower Greensand fossils, among which *Ammonites Deshayesii* may be mentioned. These facts show how closely related were the faunas of the Wealden and Cretaceous periods.

At different heights in the Hastings Sand, we find again and again slabs of sandstone with a strong ripple-mark, and between these slabs beds of clay many yards thick. In some places, as at Stammerham, near Horsham, there are indications of this clay having been exposed so as to dry and crack before the next layer was thrown down upon it. The open cracks in the clay have served as moulds, of which casts have been taken in relief, and which are, therefore, seen on the lower surface of the sandstone (see fig. 311.).

Fig. 311.



Underside of slab of sandstone about one yard in diameter.
Stammerham, Sussex.

Near the same place a reddish sandstone occurs in which are innumerable traces of a fossil vegetable, apparently *Sphenopteris*, the stems and branches of which are disposed as if the plants were standing erect on the spot where they originally grew, the sand having been gently deposited upon and around them; and similar appearances have been remarked in other places in this formation.* In the same division also of the Wealden, at Cuckfield, is a bed of gravel or conglomerate, consisting of water-worn pebbles of quartz and jasper, with rolled bones of reptiles. These must have been drifted by a current, probably in water of no great depth.

Fig. 312.

Sphenopteris gracilis (Fitton), from the Hastings Sands near Tunbridge Wells. *a*. a portion of the same magnified.

From such facts we may infer that, notwithstanding the great thickness of this division of the Wealden, the whole of it was a deposit in water of a moderate depth, and often extremely shallow. This idea may seem startling at first, yet such would be the natural consequence of a gradual and continuous sinking of the ground in an estuary or bay, into which a great river discharged its turbid waters. By each foot of subsidence, the fundamental rock would be depressed one foot farther from the surface; but the bay would not be deepened, if newly deposited mud and sand should raise the bottom one foot. On the contrary, such new strata of sand and mud might be frequently laid dry at low water, or overgrown for a season by a vegetation proper to marshes.

Area of the Wealden. — In regard to the geographical extent of the Wealden, it cannot be accurately laid down; because so much of it is concealed beneath the newer marine formations. It has been traced about 200 English miles from west to east, from the coast of Dorsetshire to near Boulogne, in France; and nearly 200 miles from north-west to south-east, from Surrey and Hampshire to Beauvais, in France. If the formation be continuous throughout this space, which is very doubtful, it does not follow that the whole was contemporaneous; because, in all likelihood, the physical geography of the region underwent frequent changes throughout the whole period, and the estuary may have altered its form, and even shifted its place. Dr. Dunker, of Cassel, and H. Von Meyer, in an excellent monograph on the Wealdens of Hanover and Westphalia, have shown that they correspond so closely, not only in their fossils, but also in their mineral characters, with the English series, that we can scarcely hesitate to refer the whole to one great delta. Even then, the magnitude of the deposit may not exceed that of many modern rivers. Thus, the delta of the Quorra or Niger, in Africa, stretches into the interior for more than 170 miles, and occupies, it is supposed, a space of more than 300 miles along the coast, thus forming a surface of more than 25,000 square miles, or equal to about one half of England.† Besides, we know not, in such cases, how far the fluviatile sediment and organic

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* Mantell, Geol. of S. E. of England, p. 244.

† Fitton, Geol. of Hastings, p. 58.; who cites Lander's Travels.

remains of the river and the land may be carried out from the coast, and spread over the bed of the sea. I have shown, when treating of the Mississippi, that a more ancient delta, including species of shells, such as now inhabit Louisiana, has been upraised, and made to occupy a wide geographical area, while a newer delta is forming *; and the possibility of such movements, and their effects, must not be lost sight of when we speculate on the origin of the Wealden.

If it be asked where the continent was placed from the ruins of which the Wealden strata were derived, and by the drainage of which a great river was fed, we are half tempted to speculate on the former existence of the Atlantis of Plato. The story of the submergence of an ancient continent, however fabulous in history, must have been true again and again as a geological event.

The real difficulty consists in the persistence of a large hydrographical basin, from whence a great body of fresh water was poured into the sea, precisely at a period when the neighbouring area of the Wealden was gradually going downwards 1000 feet or more perpendicularly. If the adjoining land participated in the movement, how could it escape being submerged, or how could it retain its size and altitude so as to continue to be the source of such an inexhaustible supply of fresh water and sediment? In answer to this question, we are fairly entitled to suggest that the neighbouring land may have been stationary, or may even have undergone a contemporaneous slow upheaval. There may have been an ascending movement in one region, and a descending one in a contiguous parallel zone of country; just as the northern part of Scandinavia is now rising, while the middle portion (that south of Stockholm) is unmoved, and the southern extremity in Scania is sinking, or at least has sunk within the historical period.† We must, nevertheless, conclude, if we adopt the above hypothesis, that the depression of the land became general throughout a large part of Europe at the close of the Wealden period, and this subsidence brought in the cretaceous ocean.

FLORA OF THE LOWER CRETACEOUS AND WEALDEN PERIOD.

The terrestrial plants of the Upper Cretaceous epoch are but little known, as might be expected, since the rocks are of purely marine origin, formed for the most part far from land. But the Lower Cretaceous or Neocomian vegetation, including that of the Weald Clay and Hastings Sands, is by no means scanty. M. Adolphe Brongniart, when dividing the whole fossiliferous series into three groups in reference solely to fossil plants, has named the primary strata "the age of acrogens;" the secondary, exclusive of the cretaceous, "the age of gymnogens;" and the third, comprising

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* See above, p. 84.; and Second Visit to the U. S. vol. ii. chap. xxxiv.

† See the Author's Annivers. Address, Geol. Soc. 1850, Quart. Geol. Journ. vol. vi. p. 52.

the cretaceous and tertiary, "the age of angiosperms."* He considers the lower cretaceous flora as displaying a transitional character from that of a secondary to that of a tertiary vegetation. *Coniferæ* and *Cycadeæ* (or Gymnogens) still flourished, as in the preceding oolitic and triassic epochs; but, together with these, some well-marked leaves of dicotyledonous trees, of a genus named *Credneria*, have long been known. They are met with in the "quader-sandstein" and "pläner-kalk" of Germany, rocks of the Upper Cretaceous group. More recently, Dr. Deby has discovered in the Lower Cretaceous beds of Aix-la-Chapelle a great variety of dicotyledonous leaves †, belonging to no less, according to his enumeration, than 26 species, some of the leaves being from four to six inches in length, and in a beautiful state of preservation. In the absence ot the organs of fructification and of fossil fruits, the number of species may be exaggerated; but we may certainly affirm, reasoning from our present data, that when the lower chalk of Aix-la-Chapelle originated, Dicotyledonous Angiosperms flourished in that region in equal proportions with Gymnosperms. This discovery has an important bearing on some popular theories, for until lately none of these Exogens (a class now constituting three fourths of the living plants of the globe) had been detected in any strata older than the Eocene. Moreover, some geologists have wished to connect the rarity of dicotyledonous trees with a peculiarity in the state of the atmosphere in the earlier ages of the planet, imagining that a denser air and noxious gases, especially carbonic acid gas being in excess, were adverse to the prevalence, not only of the quick-breathing classes of animals (mammalia and birds), but to a flora like that now existing, while it favoured the predominance of reptile life, and a cryptogamic and gymnospermous flora. The co-existence, therefore, of Dicotyledonous Angiosperms in abundance with Cycads and Coniferæ, and with a rich reptilian fauna, comprising the Iguanodon, Megalosaurus, Hylæosaurus, Ichthyosaurus, Plesiosaurus, and Ptero-

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* In this and subsequent remarks on fossil plants I shall often use Dr. Lindley's terms, as most familiar in this country; but as those of M. A. Brongniart are much cited, it may be useful to geologists to give a table explaining the corresponding names of groups so much spoken of in palæontology.

	Brongniart.	Lindley.	
Cryptogamic.	1. Cryptogamous amphigens, or cellular cryptogamic.	Thallogens.	Lichens, sea-weeds, fungi.
	2. Cryptogamous acrogens.	Acrogens.	Mosses, equisetums, ferns, lycopodiums,—Lepidodendron.
Phanerogamic.	3. Dicotyledonous gymnosperms.	Gymnogens.	Conifers and Cycads.
	4. Dicot. Angiosperms.	Exogens.	Compositæ, leguminosæ, umbelliferæ, cruciferæ, heaths, &c. All native European trees except conifers.
	5. Monocotyledons.	Endogens.	Palms, lilies, aloes, rushes, grasses, &c.

† Geol. Quart. Jour. vol. vii. part 2. Miscell. p. 111.

dactyl, in the Lower Cretaceous series, tends manifestly to dispel the idea of a meteorological state of things in the secondary periods so widely distinct from that now prevailing.

Among the recent additions made to the fossil flora of the Wealden, and one which supplies a new link between it and the tertiary flora, I may mention the *Gyrogonites*, or spore-vessels of the *Chara*, lately found in the Hastings series of the Isle of Wight.

CHAPTER XIX.

DENUDATION OF THE CHALK AND WEALDEN.

Physical geography of certain districts composed of Cretaceous and Wealden strata —Lines of inland chalk-cliffs on the Seine in Normandy—Outstanding pillars and needles of chalk—Denudation of the chalk and Wealden in Surrey, Kent, and Sussex—Chalk once continuous from the North to the South Downs—Anticlinal axis and parallel ridges—Longitudinal and transverse valleys—Chalk escarpments—Rise and denudation of the strata gradual—Ridges formed by harder, valleys by softer beds—At what periods the Weald Valley was denuded—Why no alluvium, or wreck of the chalk, in the central district of the Weald—Land has most prevailed where denudation has been greatest—Elephant bed, Brighton—Sangatte Cliff—Conclusion.

All the fossiliferous formations may be studied by the geologist in two distinct points of view: first, in reference to their position in the series, their mineral character and fossils; and, secondly, in regard to their physical geography, or the manner in which they now enter, as mineral masses, into the external structure of the earth; forming the bed of lakes and seas, or the surface or foundation of hills and valleys, plains and table-lands. Some account has already been given, on the first head, of the Tertiary, the Cretaceous, and the Wealden strata; and we may now proceed to consider certain features in the physical geography of these groups as they occur in parts of England and France.

The hills composed of white chalk in the S. E. of England have a smooth rounded outline, and, being usually in the state of sheep-pastures, are free from trees or hedgerows; so that we have an opportunity of observing how the valleys by which they are drained ramify in all directions, and become wider and deeper as they descend. Although these valleys are now for the most part dry, except during heavy rains and the melting of snow, they may have been due to aqueous denudation, as explained in the sixth chapter; having been excavated when the chalk emerged gradually from the sea. This opinion is confirmed by the occasional occurrence of what appear to be long lines of inland cliffs, in which the strata are cut off abruptly in steep and often vertical precipices. The true nature of such escarpments is nowhere more obvious than in parts of Normandy, where the river Seine and its tributaries flow through deep winding valleys, hollowed out of chalk horizontally stratified. Thus, for example, if we follow the Seine for a distance of about 30 miles from Andelys to Elbœuf, we find the valley flanked on both sides by a steep slope of chalk, with numerous beds of flint, the formation being laid open for a thickness of about 250 and 300 feet. Above the chalk is an overlying mass of sand, gravel, and clay, from 30 to 100 feet thick. The two opposite slopes of the hills *a* and *b*, fig. 313., where the chalk appears at the surface, are from 2 to 4 miles apart, and they are often perfectly smooth and even, like the steepest of our downs in England; but at many points they are broken by one, two, or more ranges of vertical and even overhanging cliffs of bare white chalk with flints. At some points detached needles and pinnacles stand in the line of the cliffs, or in front of them, as at *c*, fig. 313. On the right bank of the Seine, at Andelys, one range, about 2 miles long, is seen varying from 50 to 100 feet in perpendicular height, and having its continuity broken by a number of dry valleys or coombs, in one of which occurs a detached rock or needle, called the Tête d'Homme (see figs. 314, 315.). The top of this rock presents a precipitous face towards every point of the compass; its vertical height being more than 20 feet on the side of the downs, and 40 towards the Seine, the average diameter of the pillar being 36 feet. Its composition is the same as that of the larger cliffs in

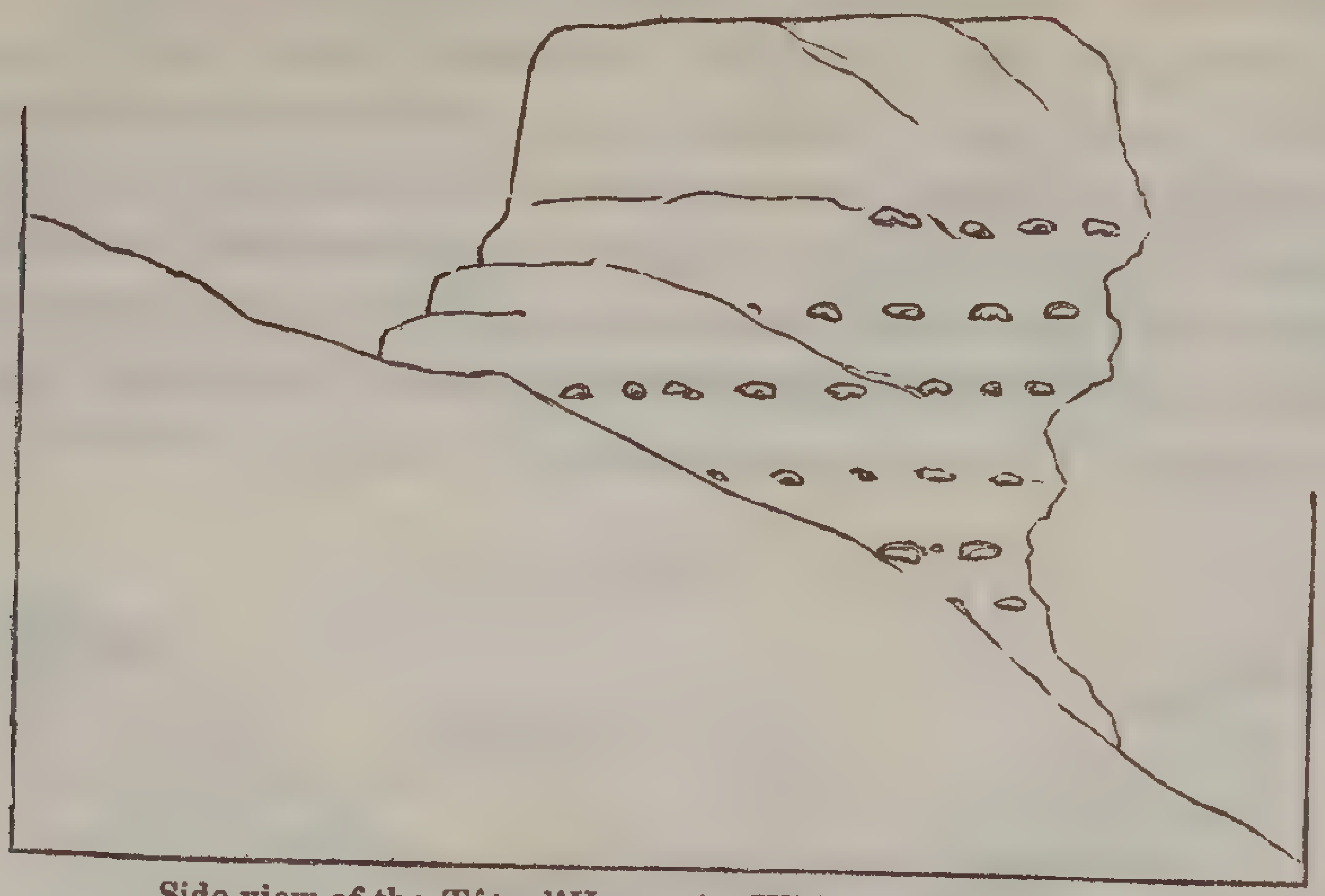
Fig. 313.

Section across Valley of Seine.

Fig. 314.

View of the Tête d'Homme, Andelys, seen from above.

Fig. 315.



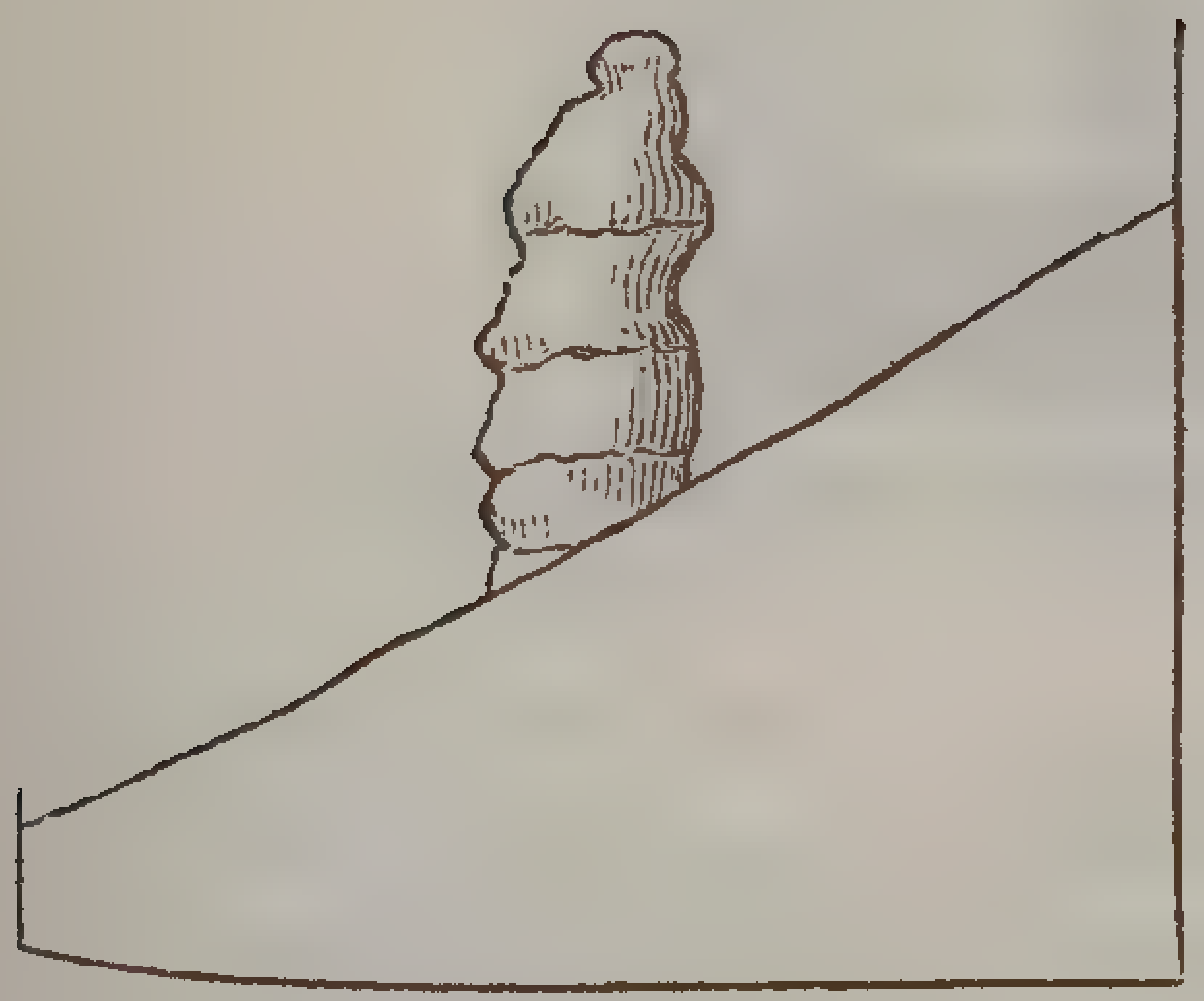
Side view of the Tête d'Homme. White chalk with flints.

its neighbourhood, namely, white chalk, having occasionally a crystalline texture like marble, with layers of flint in nodules and tabular masses. The flinty beds often project in relief 4 or 5 feet beyond the white chalk, which is generally in a state of slow decomposition, either exfoliating or being covered with white powder, like the chalk cliffs on the English coast; and, as in them, this superficial powder contains in some places common salt.

Other cliffs are situated on the right bank of the Seine, opposite Tournedos, between Andelys and Pont de l'Arche, where the precipices are from 50 to 80 feet high: several of their summits terminate in pinnacles; and one of them, in particular, is so completely detached as to present a perpendicular face 50 feet high towards the sloping down. On these cliffs several ledges are seen, which mark so many levels at which the waves of the sea may be supposed to have encroached for a long period. At a still greater height, immediately above the top of this range, are three much smaller cliffs, each about 4 feet high, with as many intervening terraces, which are continued so as to sweep in a semicircular form round an adjoining coomb, like those in Sicily before described (p. 76.).

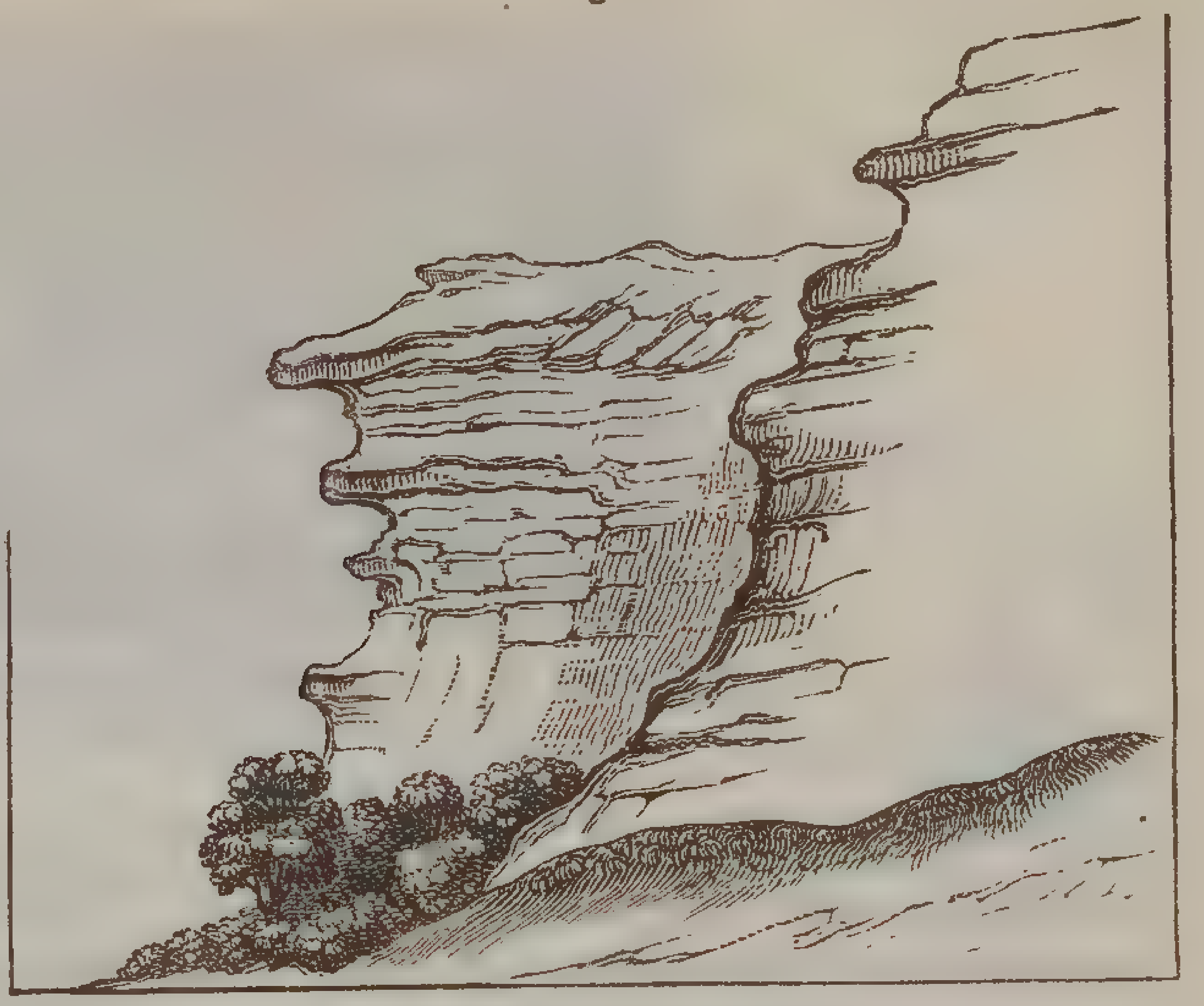
If we then descend the river from Vatteville to a place called Senneville, we meet with a singular needle about 50 feet high, perfectly isolated on the escarpment of chalk on the right bank of the Seine (see fig. 316.). Another conspicuous range of inland cliffs is situated about 12 miles below on the left bank of the Seine, beginning at Elbœuf, and comprehending the Roches d'Orival (see fig. 317.). Like those before described, it has an irregular surface, often overhanging, and with beds of flint projecting several feet. Like them, also, it exhibits a white powdery surface, and consists entirely of horizontal chalk with flints. It is 40 miles inland; its height, in some parts, exceeds 200 feet; and its base is only a few feet above the level of the Seine. It is broken, in one place, by a pyramidal mass or needle, 200 feet high, called the Roche de Pignon, which stands out about 25 feet in front of the upper portion of the main cliffs.

Fig. 316.



Chalk pinnacle at Senneville.

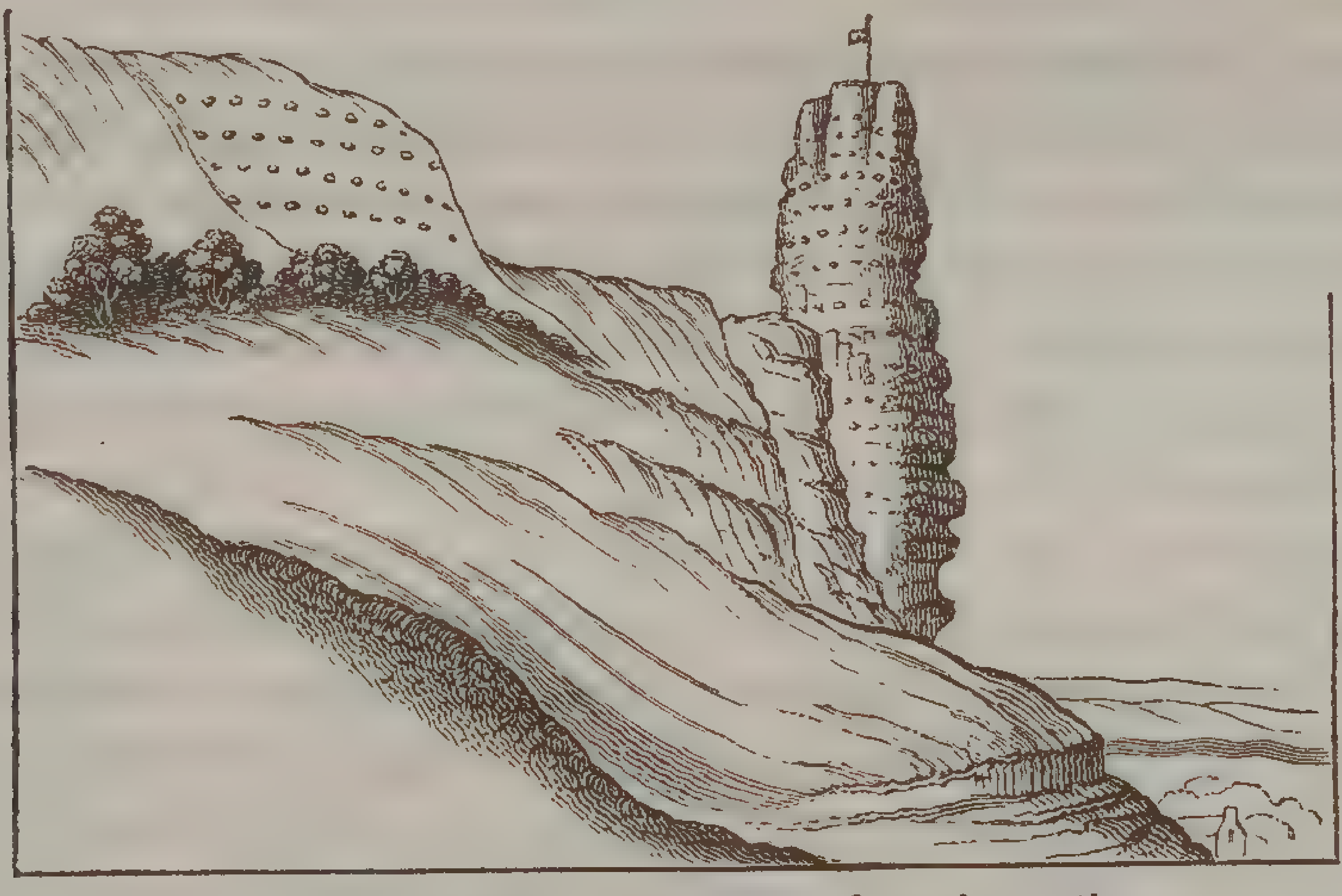
Fig. 317.



Roches d'Orival, Elbœuf.

with which it is united by a narrow ridge about 40 feet lower than its summit (see fig. 318.). Like the detached rocks before mentioned at Senneville, Vatteville, and Andelys, it may be compared to those needles of chalk which occur on the coast of Normandy* (see fig. 319.), as well as in the Isle of Wight and in Purbeck.

Fig. 318.



View of the Roche de Pignon, seen from the south.

The foregoing description and drawings will show, that the evidence of certain escarpments of the chalk having been originally sea-cliffs, is far more full and satisfactory in France than in England. If it be asked why, in the interior of our own country, we meet with no ranges of precipices equally vertical and overhanging, and no isolated pillars or needles, we may reply that the greater hardness of the chalk in Normandy may, no doubt, be the chief cause of this difference. But the frequent absence of all signs of littoral denuda-

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* An account of these cliffs was read by the author to the British Assoc. at Glasgow, Sept. 1840.

Fig. 319.

Needle and Arch of Etretat, in the chalk cliffs of Normandy. Height of Arch 100 feet. (Passy.)*

tion in the valley of the Seine itself is a negative fact of a far more striking and perplexing character. The cliffs, after being almost continuous for miles, are then wholly wanting for much greater distances, being replaced by a green sloping down, although the beds remain of the same composition, and are equally horizontal; and although we may feel assured that the manner of the upheaval of the land, whether intermittent or not, must have been the same at those intermediate points where no cliffs exist, as at others where they are so fully developed. But, in order to explain such apparent anomalies, the reader must refer again to the theory of denudation, as expounded in the 6th chapter; where it was shown, first, that the undermining force of the waves and marine currents varies greatly at different parts of every coast; secondly, that precipitous rocks have often decomposed and crumbled down; and thirdly, that terraces and small cliffs may occasionally lie concealed beneath a talus of detrital matter.

Denudation of the Weald Valley.—No district is better fitted to illustrate the manner in which a great series of strata may have been upheaved and gradually denuded than the country intervening between the North and South Downs. This region, of which a groundplan is given in the accompanying map (fig. 320.), comprises within it the whole of Sussex, and parts of the counties of Kent, Surrey, and Hampshire. The space in which the formations older than the White Chalk, or those from the Gault to the Hastings sands inclusive, crop out, is bounded everywhere by a great escarpment of chalk, which is continued on the opposite side of the channel in the Bas Boulonnais in France, where it forms the semicircular boundary of a tract in which older strata also appear at the surface. The whole of this district may therefore be considered geologically as one and the same.

The space here inclosed within the escarpment of the chalk affords an example of what has been sometimes called a "valley of elevation" (more properly "of denudation"); where the strata, partially removed by aqueous excavation, dip away on all sides from a central axis. Thus, it is supposed that the area now occupied by the

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* Seine-Inferieure, p. 142. and pl. 6. fig. 1.

Fig. 320.

Geological Map of the south-east of England, and part of France, exhibiting the denudation of the Weald.

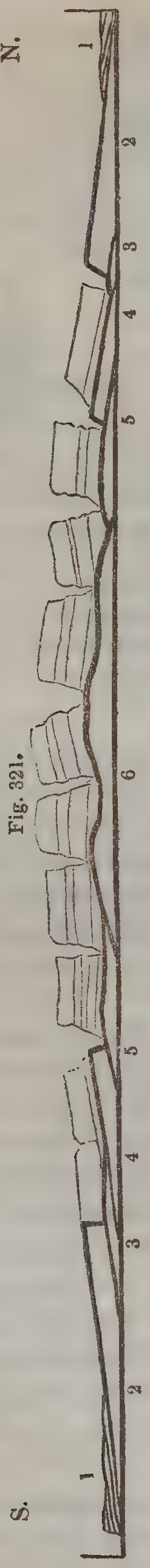
1. ▥ Tertiary.
2. □ Chalk and Upper Greensand.
3. ▬ Gault.
4. ▤ Lower Greensand.
5. ▦ Weald clay.
6. ░ Hastings sands.
7. ▨ Purbeck beds.
8. ▧ Oolite.

Hastings sand (No. 6.) was once covered by the Weald clay (No. 5.), and this again by the Greensand (No. 4.), and this by the Gault (No. 3.); and, lastly, that the Chalk (No. 2.) extended originally over the whole space between the North and the South Downs. This theory will be better understood by consulting the annexed diagram (fig. 321.), where the dark lines represent what now remains, and the fainter ones those portions of rock which are believed to have been carried away.

At each end of the diagram the tertiary strata (No. 1.) are exhibited reposing on the chalk. In the middle are seen the Hastings sands (No. 6.) forming an anticlinal axis, on each side of which the other formations are arranged with an opposite dip. It has been necessary, however, in order to give a clear view of the different formations, to exaggerate the proportional height of each in comparison to its horizontal extent; and a true scale is therefore subjoined in another diagram (fig. 322.), in order to correct the erroneous impression which might otherwise be made on the reader's mind. In this section the distance between the North and South Downs is represented to exceed forty miles; for the Valley of the Weald is here intersected in its longest diameter, in the direction of a line between Lewes and Maidstone.

Through the central portion, then, of the district supposed to be denuded runs a great anticlinal line, having a direction nearly east and west, on both sides of which the beds 5, 4, 3, and 2 crop out in succession. But, although, for the sake of rendering the physical structure of this region more intelligible, the central line of elevation has alone been introduced, as in the diagrams of Smith, Mantell, Conybeare, and others, geologists have always been well aware that

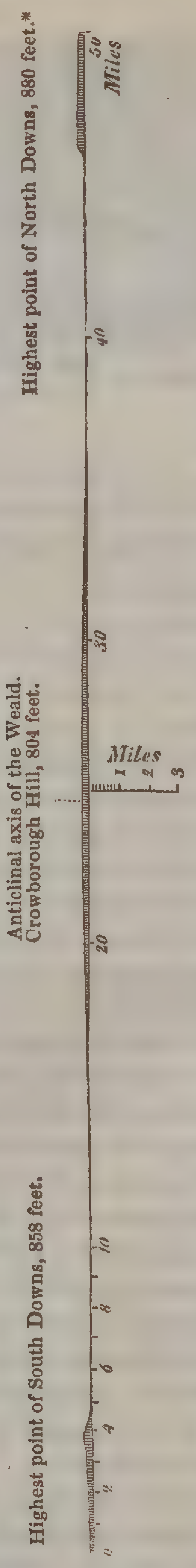
Fig. 321.



Section from the London to the Hampshire basin across the valley of the Weald.

1. Tertiary strata. 2. Chalk and firestone. 3. Gault. 4. Lower greensand. 5. Weald clay. 6. Hastings sands.

Fig. 322.



Section of the country from the confines of the basin of London to that of Hants, with the principal heights above the level of the sea on a true scale.

numerous minor lines of dislocation and flexure run parallel to the great central axis.

In the central area of the Hastings sand the strata have undergone the greatest displacement; one fault being known, where the

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* Botley Hill, near Godstone, in Surrey, was found by trigonometrical measurement to be 880 feet above the level of the sea; and Wrotham Hill, near Maidstone, which appears to be next in height of the North Downs, 795 feet.

vertical shift of a bed of calcareous grit is no less than 60 fathoms.* Much of the picturesque scenery of this district arises from the depth of the narrow valleys and ridges to which the sharp bends and fractures of the strata have given rise; but it is also in part to be attributed to the excavating power exerted by water, especially on the interstratified argillaceous beds.

Fig. 323.

View of the chalk escarpment of the South Downs. Taken from the Devil's Dike, looking towards the west and south-west.

a. The town of Steyning is hidden by this point. *b.* Edburton church. *c.* Road. *d.* River Adur.

Besides the series of longitudinal valleys and ridges in the Weald, there are valleys which run in a transverse direction, passing through the chalk to the basin of the Thames on the one side, and to the English Channel on the other. In this manner the chain of the North Downs is broken by the rivers Wey, Mole, Darent, Medway, and Stour; the South Downs by the Arun, Adur, Ouse, and Cuckmere.† If these transverse hollows could be filled up, all the rivers, observes Dr. Conybeare, would be forced to take an easterly course, and to empty themselves into the sea by Romney Marsh and Pevensey Levels.

Mr. Martin has suggested that the great cross fractures of the chalk, which have become river-channels, have a remarkable correspondence on each side of the valley of the Weald; in several instances the gorges in the North and South Downs appearing to be directly opposed to each other. Thus, for example, the defiles of the Wey in the North Downs, and of the Arun in the South, seem to coincide in direction; and, in like manner, the Ouse corresponds to the Darent, and the Cuckmere to the Medway.‡

Although these coincidences may, perhaps, be accidental, it is by no means improbable, as

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* Fitton, Geol. of Hastings, p. 55.

† Conybeare, Outlines of Geol., p. 81.

‡ Geol. of Western Sussex, p. 61.

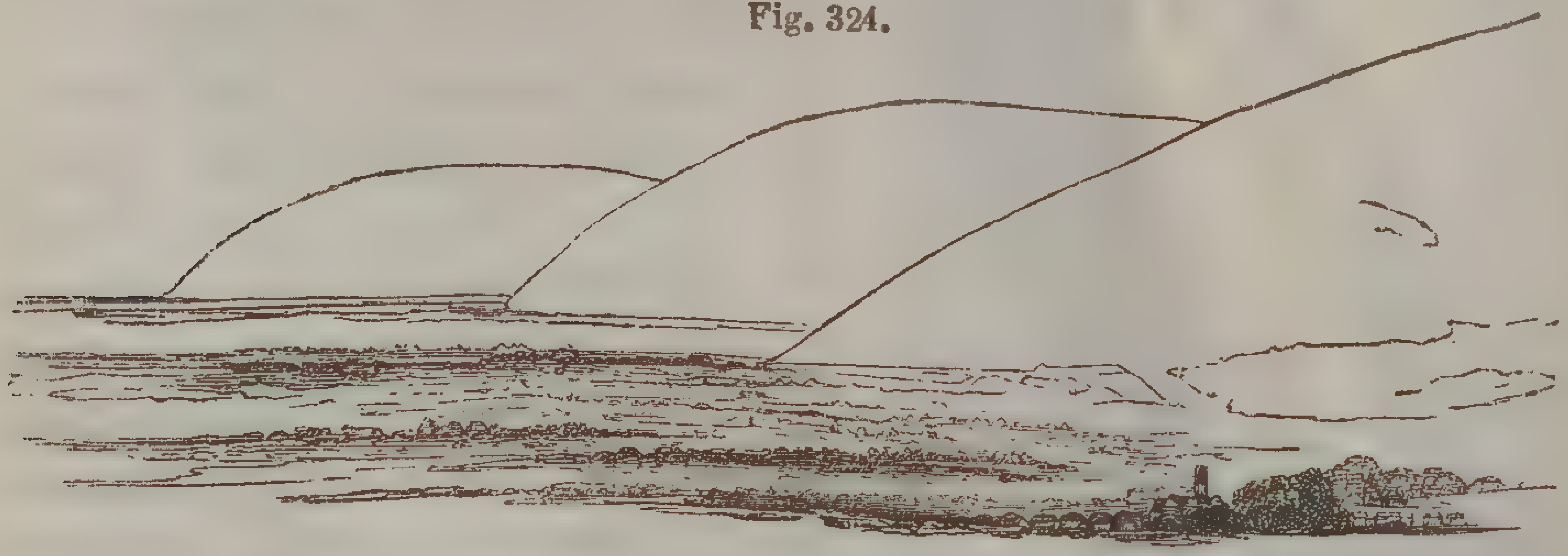
hinted by the author above mentioned, that great amount of elevation towards the centre of the Weald district gave rise to transverse fissures. And as the longitudinal valleys were connected with that linear movement which caused the anticlinal lines running east and west, so the cross fissures might have been occasioned by the intensity of the upheaving force towards the centre of the line.

But before treating of the manner in which the upheaving movement may have acted, I shall endeavour to make the reader more intimately acquainted with the leading geographical features of the district, so far as they are of geological interest.

In whatever direction we travel from the tertiary strata of the basins of London and Hampshire towards the valley of the Weald, we first ascend a slope of white chalk, with flints, and then find ourselves on the summit of a declivity consisting, for the most part, of different members of the chalk formation; below which the Upper Greensand, and sometimes, also, the Gault, crop out. This steep declivity is the great escarpment of the chalk before mentioned, which overhangs a valley excavated chiefly out of the argillaceous or marly bed, termed Gault (No. 3.). The escarpment is continuous along the southern termination of the North Downs, and may be traced from the sea, at Folkestone, westward to Guildford and the neighbourhood of Petersfield, and from thence to the termination of the South Downs at Beachy Head. In this precipice or steep slope the strata are cut off abruptly, and it is evident that they must originally have extended farther. In the wood-cut (fig. 323. p. 275.) part of the escarpment of the South Downs is faithfully represented, where the denudation at the base of the declivity has been somewhat more extensive than usual, in consequence of the Upper and Lower Greensand being formed of very incoherent materials, the former, indeed, being extremely thin and almost wanting.

The geologist cannot fail to recognise in this view the exact likeness of a sea-cliff; and if he turns and looks in an opposite direction, or eastward, towards Beachy Head (see fig. 324.), he will see the same line of heights prolonged. Even those who are not accustomed to speculate on the former changes which the surface has undergone may fancy the broad and level plain to resemble the flat sands which were laid dry by the receding tide, and the different

Fig. 324.



Chalk escarpment, as seen from the hill above Steyning, Sussex. The castle and village of Bramber in the foreground.

projecting masses of chalk to be the headlands of a coast which separated the different bays from each other.

Occasionally in the North Downs sand-pipes are intersected in the slope of the escarpment, and have been regarded by some geologists as more modern than the slope; in which case they might afford an argument against the theory of these slopes having originated as sea-cliffs or river-cliffs. But, when we observe the great depth of many sand-pipes, those near Sevenoaks, for example, we perceive that the lower termination of such pipes must sometimes appear at the surface far from the summit of an escarpment, whenever portions of the chalk are cut away.

Fig. 325.

Transverse Valley of the Adur in the South Downs.

a. Town of Steyning. *b.* River Adur. *c.* Old Shoreham.

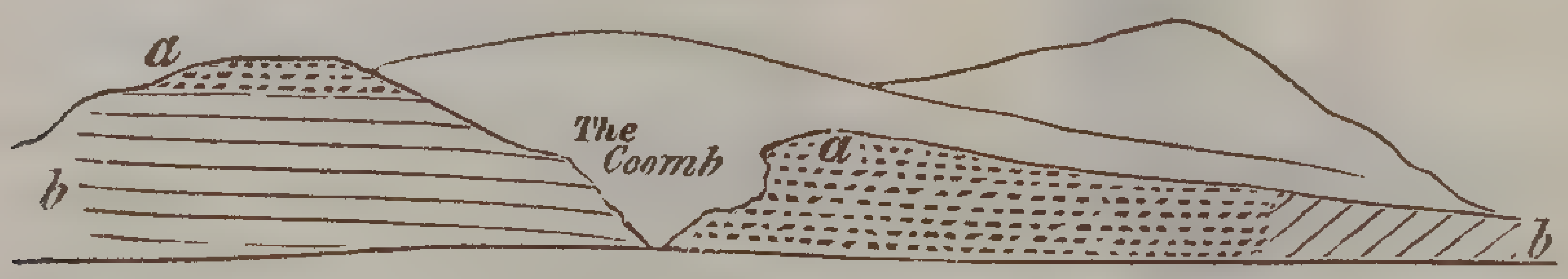
In regard to the transverse valleys before mentioned, as intersecting the chalk hills, some idea of them may be derived from the subjoined sketch (fig. 325.) of the gorge of the River Adur, taken from the summit of the chalk-downs, at a point in the bridle-way leading from the towns of Bramber and Steyning to Shoreham. If the reader will refer again to the view given in a former woodcut (fig. 323. p. 275.), he will there see the exact point where the gorge of which I am now speaking interrupts the chalk escarpment. A projecting hill, at the point *a*, hides the town of Steyning, near which the valley commences where the Adur passes directly to the sea at Old Shoreham. The river flows through a nearly level plain, as do most of the others which intersect the hills of Surrey, Kent, and Sussex; and it is evident that these openings could not have been produced by rivers, except under conditions of physical geography entirely different from those now prevailing. Indeed, many of the existing rivers, like the Ouse near Lewes, have filled up arms of the sea, instead of deepening the hollows which they traverse.

That the place of some, if not of all, the gorges running north and south, has been originally determined by the fracture and displacement of the rocks, seems the more probable, when we reflect on the proofs obtained of a ravine running east and west, which branches off from the eastern side of the valley of the Ouse just mentioned, and which is undoubtedly due to dislocation. This ravine is called "the Coomb" (fig. 326.), and is situated in the suburbs of the town of Lewes. It was first traced out by Dr. Mantell, in whose company I examined it. The steep declivities on each side are covered with green turf, as is the bottom, which is perfectly dry. No outward signs of disturbance are visible; and the connection of the hollow with subterranean movements would not have been suspected by the geologist, had not the evidence of great convulsions been clearly exposed in the escarpment of the valley of the Ouse, and the numerous chalk-pits worked at the termination of the Coomb. By the aid of these we discover that the ravine coincides precisely with a line of fault, on one side of which the chalk with flints (*a*, fig. 327.) appears at the summit of the hill, while it is thrown down to the bottom on the other.

Fig. 326.

The Coomb, near Lewes.

Fig. 327.



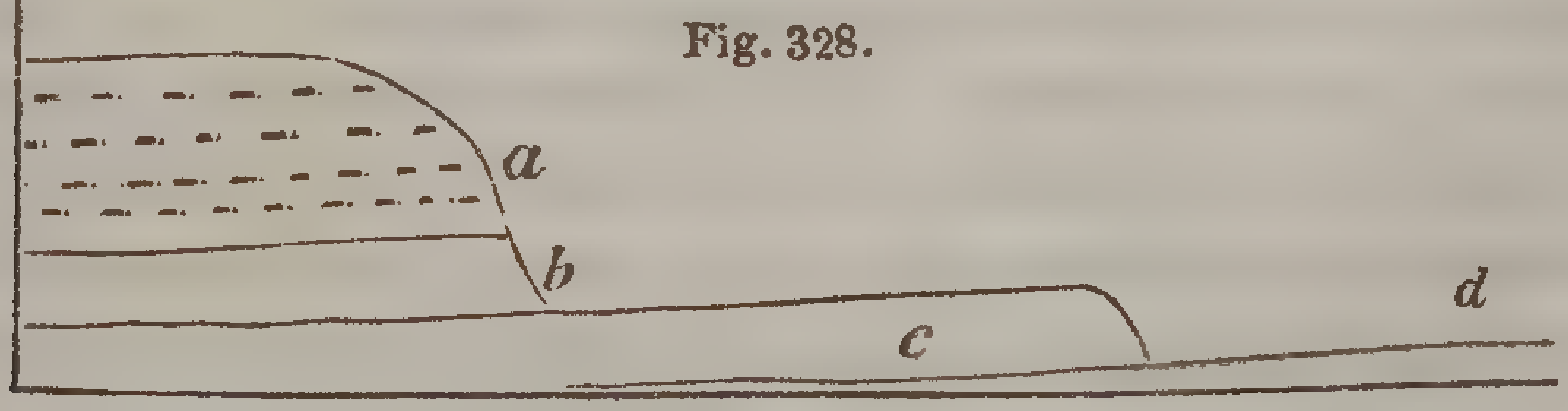
Fault coinciding with the Coomb, in the Cliff-hill near Lewes. Mantell.
a. Chalk with flints. *b*. Lower chalk.

In order to account for the manner in which the five groups of strata, 2, 3, 4, 5, 6, represented in the map, fig. 320., and in the section, fig. 321., may have been brought into their present position, the following hypothesis has been suggested:— Suppose the five formations to lie in horizontal stratification at the bottom of the sea; then let a movement from below press them upwards into the form of a flattened dome, and let the crown of this dome be afterwards cut off, so that the incision should penetrate to the lowest of the five groups. The different beds would then be exposed on the surface, in the manner exhibited in the map, fig. 320.*

The quantity of denudation, or removal by water, of stratified masses assumed to have once reached continuously from the North to the South Downs is so enormous, that the reader may at first be startled by the boldness of the hypothesis. But the difficulty will disappear when once sufficient time is allowed for the gradual rising and sinking of the strata at many successive geological periods, during which the waves and currents of the ocean, and the power of rain, rivers, and land-floods, might slowly accomplish operations which no sudden diluvial rush of waters could possibly effect.

Among other proofs of the action of water, it may be stated that the great longitudinal valleys follow the outcrop of the softer and more incoherent beds, while ridges or lines of cliff usually occur at those points where the strata are composed of harder stone. Thus, for example, the chalk with flints, together with the subjacent upper greensand, which is often used for building, under the provincial name of "firestone," have been cut into a steep cliff on that side on which the sea encroached. This escarpment bounds a deep valley, excavated chiefly out of the soft argillaceous bed, termed gault (No. 3., map, p. 273.). In some places the upper greensand is in a loose and incoherent state, and there it has been as much denuded as the gault; as, for example, near Beachy Head; but farther to the westward it is of great thickness, and contains hard beds of blue chert and calcareous sandstone or firestone. Here, accordingly, we find that it produces a corresponding influence on the scenery of the country; for it runs out like a step beyond the foot of the chalk-hills, and constitutes a lower terrace, varying in breadth from a quarter of a mile to three miles, and following the sinuosities of the chalk-escarpment.†

Fig. 328.



a. Chalk with flints. *b.* Chalk without flints.
c. Upper greensand, or firestone. *d.* Gault.

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* See illustrations of this theory, by Dr. Fitton, Geol. Sketch of Hastings.

† Sir R. Murchison, Geol. Sketch of Sussex, &c., Geol. Trans., Second Series, vol. ii. p. 98.

It is impossible to desire a more satisfactory proof that the escarpment is due to the excavating power of water during the rise of the strata, or during their rising and sinking at successive periods; for I have shown, in my account of the coast of Sicily (p. 76.), in what manner the encroachments of the sea tend to efface that succession of terraces which must otherwise result from the intermittent upheaval of a coast preyed upon by the waves. During the interval between two elevatory movements, the lower terrace will usually be destroyed, wherever it is composed of incoherent materials; whereas the sea will not have time entirely to sweep away another part of the same terrace, or lower platform, which happens to be composed of rocks of a harder texture, and capable of offering a firmer resistance to the erosive action of water. As the yielding clay termed gault would be readily washed away, we find its outcrop marked everywhere by a valley which skirts the base of the chalk-hills, and which is usually bounded on the opposite side by the lower greensand; but as the upper beds of this last formation are most commonly loose and incoherent, they also have usually disappeared and increased the breadth of the valley. In those districts, however, where chert, limestone, and other solid materials enter largely into the composition of this formation (No. 4., map, p. 273.), they give rise to a range of hills parallel to the chalk, which sometimes rival the escarpment of the chalk itself in height, or even surpass it, as in Leith Hill, near Dorking. This ridge often presents a steep escarpment towards the soft argillaceous deposit called the Weald clay (No. 5.; see the dark tint in fig. 321. p. 274.), which usually forms a broad valley, separating the lower greensand from the Hastings sands or Forest Ridge; but where subordinate beds of sandstone of a firmer texture occur, the uniformity of the plain of No. 5. is broken by waving irregularities and hillocks.

Pluvial action. — In considering, however, the comparative destructibility of the harder and softer rocks, we must not underrate the power of rain. The chalk-downs, even on their summits, are usually covered with unrounded chalk-flints, such as might remain after masses of white chalk had been softened and removed by water. This superficial accumulation of the hard or siliceous materials of disintegrated strata may be due in no small degree to pluvial action; for during extraordinary rains a rush of water charged with calcareous matter, of a milk-white colour, may be seen to descend even gently sloping hills of chalk. If a layer no thicker than the tenth of an inch be removed once in a century, a considerable mass may in the course of indefinite ages melt away, leaving nothing save a stratum of flinty nodules to attest its former existence. A bed of fine clay sometimes covers the surface of slight depressions in the white chalk, which may represent the aluminous residue of the rock, after the pure carbonate of lime has been dissolved by rain-water, charged with excess of carbonic acid derived from decayed vegetable matter. The acidulous waters sometimes descend through "sand-pipes" and "swallow-holes" in the chalk, so that the surface may be undermined, and cavities may be formed or enlarged, even by that part of the drainage which is subterranean.*

Lines of Fracture.—Mr. Martin, in his work on the geology of Western Sussex, published in 1828, threw much light on the structure of the Wealden by tracing out continuously for miles the direction of many anticlinal lines and cross fractures; and the same course of investigation has since been followed out in greater detail by Mr. Hopkins. The geologist and mathematician last-mentioned has shown that the observed direction of the lines of flexure and dislocation in the Weald district coincide with those which might have been anticipated theoretically on mechanical principles, if we assume certain simple conditions under which the strata were lifted up by an expansive subterranean force.†

His opinion, that both the longitudinal and transverse lines of fracture may have been produced simultaneously, accords well with that expressed by M. Thurmann, in his work on the anticlinal ridges and valleys of elevation of the Bernese Jura.‡ For the accuracy of the map and sections of the Swiss geologist I can vouch, from personal examination, in 1835, of part of the region surveyed by him. Among other results, at which he arrived, it appears that the breadth of the anticlinal ridges and dome-shaped masses in the Jura is invariably great in proportion to the number of the formations exposed to view; or, in other words, to the depth to which the superimposed groups of secondary strata have been laid open. (See fig. 71. p. 55. for structure of Jura.) He also remarks, that the anticlinal lines are occasionally oblique and cross each other, in which case the greatest dislocation of the beds takes place. Some of the cross fractures are imagined by him to have been contemporaneous with others subsequent to the longitudinal ones.

I have assumed, in the former part of this chapter, that the rise of the Weald was gradual, whereas many geologists have attributed its elevation to a single effort of subterranean violence. There appears to them such a unity of effect in this and other lines of deranged strata in the south-east of England, such as that of the Isle of Wight, as is inconsistent with the supposition of a great number of separate movements recurring after long intervals of time. But we know that earthquakes are repeated throughout a long series of ages in the same spots, like volcanic eruptions. The oldest lavas of Etna were poured out many thousands, perhaps myriads of years before the newest, and yet they, and the movements accompanying their emission, have produced a symmetrical mountain; and if rivers of melted matter thus continue to flow upwards in the same direction, and towards the same point, for an indefinite lapse of ages, what difficulty is there in conceiving that the subterranean volcanic force, occasioning the rise or fall of certain parts of the earth's crust,

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* See above, p. 82, 83. "Sand-pipes in Chalk;" and Prestwich, Geol. Quart. Journ. vol. x. p. 222.

† Geol. Soc. Proceed. No. 74. p. 363. 1841, and G. S. Trans. 2 Ser. vol. 7.

‡ Soulèvemens Jurassiques. 1832.

may, by reiterated movements, produce the most perfect unity of result?

At what periods the Weald valley was denuded.—We may next inquire at what time the denudation of the Weald was effected, and we shall find, on considering all the facts brought to light by recent investigation, that it was accomplished in the course of so long a series of ages, that the greatest revolutions in the physical geography of the globe, yet known to us, have taken place within the same lapse of time. It has now been ascertained, that part of the denudation of the Weald was completed before the British Eocene strata, and consequently before the nummulitic rocks of Europe and Asia were formed. The date, therefore, of part of the changes now under contemplation was long antecedent to the existence of the Alps, Pyrenees, and many other European and Asiatic mountain-chains, and even to the accumulation of large portions of their component materials beneath the sea.

M. Elie de Beaumont suggested, in 1833, that there was an island in the Eocene sea in the area now occupied by the French and English Wealden strata, and he gave a map or hypothetical restoration of the ancient geography of that region at the era alluded to.* Mr. Prestwich has since shown that the materials of which the lower tertiary beds of England are made up, and their manner of resting on the chalk, imply, that such an island, or several islands and shoals, composed of Chalk, Upper Greensand, Gault, and probably of some of the Lower Cretaceous rocks, did exist somewhere between the present North and South Downs. The undermined cliffs and shores of those lands supplied the flints, which the action of the waves rounded into pebbles, such as now form the Woolwich and Blackheath shingle-beds below the London Clay. It is supposed, that the land referred to was drained by rivers flowing into the Eocene sea, and whence the brackish and freshwater deposits of Woolwich and other contemporaneous strata† were derived. The large size of some of the rolled flints (eight inches and upwards in diameter) of the Blackheath shingle demonstrates the proximity of land. Such heavy masses could not have been transported from great distances, whether they owe their shape to waves breaking on a sea-beach, or to rivers descending a steep slope.

In the annexed diagram (fig. 329.) Mr. Prestwich has represented a section from near Saffron Walden, in Essex, to the Weald, passing north and south through Godstone, in which we see how the chalk, *c*, had been disturbed and denuded before the lower Eocene beds, *b*, were deposited. Some small patches of the last-mentioned beds, *b'*, consisting of clay and sand, extend occasionally, as in this instance, to the very edge of the escarpment of the North Downs, proving that the surface of the white chalk, now covered with tertiary strata, is the same which originally constituted the bottom of the Eocene sea.

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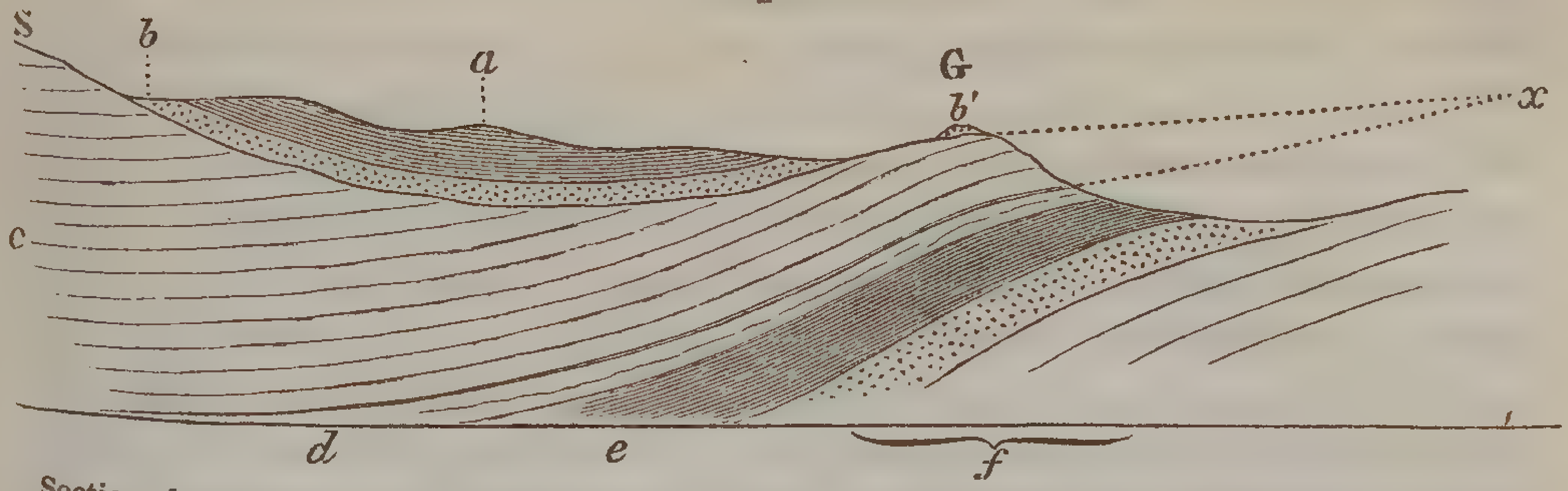
* Mém. de la Soc. Géol. de France, vol. i. part i. p. 111. pl. 7. fig. 5.

† See p. 221. above.

Fig. 329.



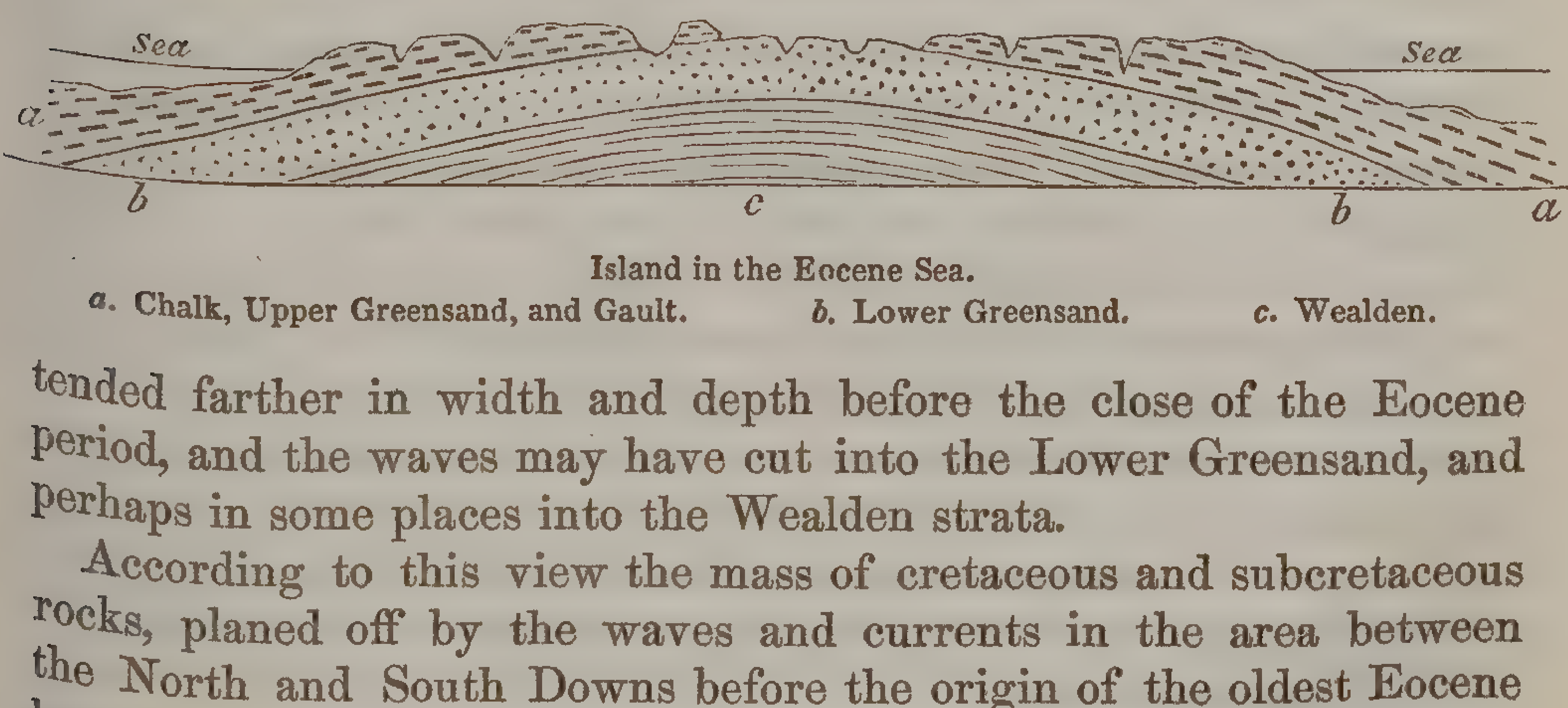
Section showing that the Weald had been denuded of chalk before the Lower Eocene strata were deposited.

S. Relative position of Saffron Walden.
G. Chalk-escarpment above Godstone, surmounted by a patch of the Lower Tertiary beds, *b′*.
a. London Clay. *b, b′.* Lower Tertiaries. *c.* Chalk.
d. Upper Greensand. *e.* Gault. *f.* Lower Greensand and Wealden.
x. Point at which the present upper and under surfaces of the chalk, if they were prolonged, would converge.

It is therefore inferred, that, if we prolong southwards the upper and under surfaces of the chalk, along the dotted line in the above section, they would converge at the point *x*; therefore, beyond that point, no white chalk existed at the time when the Eocene beds, *b*, *b′*, were formed. In other words, the central parts of the Wealden, south of *x*, were already bared of their original covering of chalk, or had only some slight patches of that rock scattered over them.

The island, or islands, in the Eocene sea may be represented in the annexed diagram (fig. 330.); but doubtless the denudation extended farther in width and depth before the close of the Eocene period, and the waves may have cut into the Lower Greensand, and perhaps in some places into the Wealden strata.

Fig. 330.



Island in the Eocene Sea.
a. Chalk, Upper Greensand, and Gault. *b.* Lower Greensand. *c.* Wealden.

According to this view the mass of cretaceous and subcretaceous rocks, planed off by the waves and currents in the area between the North and South Downs before the origin of the oldest Eocene beds, may have been as voluminous as the mass removed by denudation since the commencement of the Eocene era.

But the reader may ask, why is it necessary to assume that so much white chalk first extended continuously over the Wealden beds in this part of England, and was then removed? May we not suppose that land began to exist between the North and South Downs at a much earlier epoch; and that the upper Wealden beds rose in the midst of the Cretaceous Ocean, so as to check the accumulation of white chalk, and limit it to the deeper water of adjoining areas? This hypothesis has often been advanced, and as often rejected; for, had there been shoals or dry land so near, the white chalk would not have remained unsoiled, or without intermixture of mud and sand; nor would organic remains of terrestrial, fluviatile, or littoral origin have been so entirely wanting in the strata of the North and South Downs, where the chalk terminates abruptly in the escarpments. It is admitted that the fossils now found there belong exclusively to classes which inhabit a deep sea. Moreover, the uppermost beds of the Wealden group, as Mr. Prestwich has remarked, would not have been so strictly conformable with the lowest beds of the Lower Greensand had the strata of the Wealden undergone upheaval before the deposition of the incumbent cretaceous series.

But, although we must assume that the white chalk was once continuous over what is now the Weald, it by no means follows that the first denudation was subsequent to the entire Cretaceous era. Most probably it commenced before a large portion of the Maestricht beds were formed, or while they were in progress. I have already stated (p. 239. above), that in parts of Belgium I observed rolled pebbles of chalk-flints very abundant in the lowest Maestricht beds, where these last overlie the white chalk, showing at how early a date the chalk was upraised from deep water and exposed to aqueous abrasion.

Guided by the amount of change in organic life, we may estimate the interval between the Maestricht beds and the Thanet Sands to have been nearly equal in duration to the time which elapsed between the deposition of those same Thanet Sands and the Glacial period. If so, it would be idle to expect to be able to make ideal restorations of the innumerable phases in physical geography through which the south-east of England must have passed since the Weald began to be denuded. In less than half the same lapse of time the aspect of the whole European area has been more than once entirely changed. Nevertheless, it may be useful to enumerate some of the known fluctuations in the physical conformation of the Weald and the regions immediately adjacent during the period alluded to.

First, we have to carry back our thoughts to those very remote movements which first brought up the white chalk from a deep sea into exposed situations where the waves could plane off certain portions, as expressed in diagram, fig. 329., before the British Lower Eocene beds originated.

Secondly, we have to take into account the gradual wear and tear of the chalk and its flints, to which the Thanet sands bear witness, as well as the subsequent Woolwich and Blackheath shingle-beds, occasionally 50 feet thick, and composed of rolled flint-pebbles.

Thirdly, at a later period a great subsidence took place, by which the shallow-water and fresh-water beds of Woolwich and other Lower Eocene deposits were depressed (see above, p. 222.) so as to allow the London Clay and Bagshot series, of deep-sea origin, to accumulate over them. The amount of this subsidence, according to Mr. Prestwich, exceeded 800 feet in the London, and 1800 feet in the Hampshire or Isle of Wight basin; and, if so, the intervening area of the Weald could scarcely fail to share in the movement, and some parts at least of the island before spoken of (fig. 330. p. 283.) would become submerged.

Fourthly. After the London clay and the overlying Bagshot sands had been deposited, they appear to have been upraised in the London basin, during the Eocene period, and their conversion into land in the north seems to have preceded the upheaval of beds of corresponding age in the south, or in the Hampshire basin; because none of the fluvio-marine Eocene strata of Hordwell and the Isle of Wight (described in Ch. XVI.) are found in any part of the London area.

Fifthly. The fossils of the alternating marine, brackish, and freshwater beds of Hampshire, of Middle and Upper Eocene date, bear testimony to rivers draining adjacent lands, and to the existence of numerous quadrupeds in those lands. Instead of these phenomena, the signs of an open sea might naturally have been expected, as a consequence of the vast subsidence of the Middle Eocene beds before mentioned, had not some local upheaval taken place at the same time in the Isle of Wight or in regions immediately adjacent. Whatever hypothesis be adopted, we are entitled to assume that during the Middle and Upper Eocene periods there were risings and sinkings of land, and changes of level in the bed of the sea in the south-east of England, and that the movements were by no means uniform over the whole area during these periods. The extent and thickness of the missing beds in the Weald should of itself lead us to look for proofs of that area having by repeated oscillations changed its level frequently, and, oftener than any adjoining area, been turned from sea into land; for the submergence and emergence of land augment, beyond any other cause, the wasting and removing power of water, whether of the waves or of rivers and land-floods.

Sixthly. As yet we have discovered no marine Miocene (or *falunian*) formations in any part of the British Isles, nor any of older Pliocene date south of the Thames; but the Upper Eocene strata of the Isle of Wight (the Hempstead beds before described) have been upraised above the level of the sea in which they were originally formed, and some of them have been thrown into a vertical position, as seen in Alum and Whitecliff Bays, attesting great movements since the origin of the newest tertiaries of that district. Such movements may have occurred, in great part at least, during the Miocene period, when a large part of Europe is supposed to have become land as before suggested (p. 181.). Hence we are entitled to speculate on the probability of revolutions in the physical geography of the Weald in times intermediate between the deposition of the Hempstead beds and the origin of the Suffolk crag.

Seventhly. But we have still to consider another vast interval of time — that which separated the beginning of the older Pliocene from the beginning of the Pleistocene era, — a lapse of ages which, if measured by the fluctuations experienced in the marine fauna, may have sufficed to uplift or sink whole continents by a process as slow as that which is now operating in Sweden and in Greenland.

Lastly. The reader must recall to mind what was said, in the 11th and 12th chapters, of the glacial drift and its far-transported materials. How wide an extent of the British Isles appears to have been under the sea during some part or other of that epoch! Most of the submerged areas were afterwards converted into dry land, several hundred and in some places more than a thousand feet high. It is an opinion very commonly entertained, that the central axis of the Weald was dry land when the most characteristic northern drift originated; no traces of northern erratics having been met with farther south than Highgate near London. If such were the case, the Weald was probably dry land at the era when the buried forest of Cromer in Norfolk (see above, p. 137. and 154.) flourished, and when the elephant, rhinoceros, hippopotamus, extinct beaver, and other mammals peopled that country. It may also be presumed that the Weald continued above the sea-level when that forest sank down to receive its covering of boulder-clay, gravel, chalk-rubble, and other deposits, several hundred feet thick. But it by no means follows that the area of the Weald was stationary during all this period. Its surface may have been modified again and again during the Glacial era, though it may never have been submerged beneath the sea.

Mr. Trimmer has represented in a series of four maps his views as to the successive changes which the physical geography of England and parts of Europe may have undergone, after the commencement of the Glacial epoch.* In the last but one of these he places the Weald under water at a date long posterior to the forest of Cromer. In the fourth map he represents the Weald as reconverted into land at a time when England was united to the continent, and when the Thames was a river of greater volume and of more easterly extension than it is now, as proved by his own and Mr. Austen's observations on the ancient alluvium of the Thames with its freshwater fossils at points very near the sea. To discuss the various data on which such conclusions depend, would lead me into too long a digression; I merely allude to them in this place to show that, while the researches of Mr. Prestwich establish the extreme remoteness of the period when the denuding operations began, those of other geologists above cited, to whom Mr. Martin, Professor Morris, and Sir R. Murchison should be added, prove that important superficial changes have occurred at very modern eras.

In Denmark, especially in the island of Möen, Mr. Puggaard has demonstrated that strata of chalk with flints, nearly as thick as the white chalk of the Isle of Wight and Purbeck, have undergone disturbances and contortions since the northern drift was formed.† The layers of chalk-flint exposed in lofty sea-cliffs are often vertical and curved, and the sands and clays of the overlying drift follow the bendings and foldings of the older beds, and have evidently suffered the same derangement. If, therefore, we find it necessary, in order to

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* Geol. Quart. Journ., vol. ix. pl. 13.

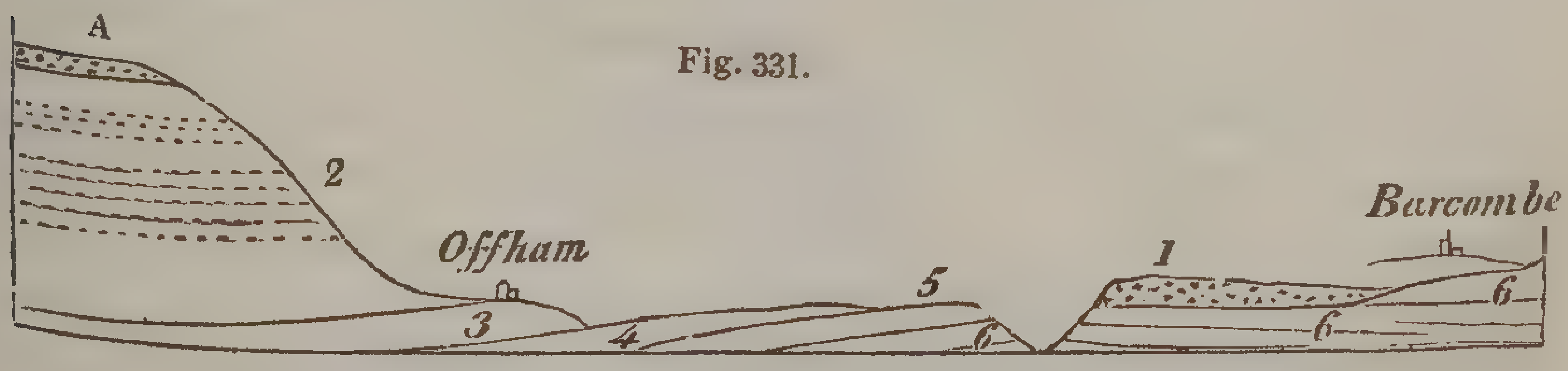
† Puggaard, Möens Geologie, 8vo. Copenhagen, 1851.

explain the position of some beds of gravel, loam, or drift in the south-east of England, to imagine important dislocations of the chalk and local changes of level since the Glacial period, such speculations are in harmony with conclusions derived from independent sources, or drawn from the exploration of foreign countries.

It was long ago observed by Dr. Mantell that no vestige of the chalk and its flints has been seen on the central ridge of the Weald or on the Hastings Sands, but merely gravel and loam derived from the rocks immediately subjacent. This distribution of alluvium, and especially the absence of chalk detritus in the central district, agrees well with the theory of denudation before set forth; for, to return to fig. 321. (p. 274.), if the chalk (No. 2.) were once continuous and covered every where with flint-gravel, this superficial covering would be the first to be carried away from the highest part of the dome long before any of the gault (No. 3.) was laid bare. Now, if some ruins of the chalk remain at first on the gault, these would be, in a great degree, cleared away before any part of the lower greensand (No. 4.) is denuded. Thus in proportion to the number and thickness of the groups removed in succession, is the probability lessened of our finding any remnants of the highest group strewed over the bared surface of the lowest.

But it is objected, that, had the sea at one or several periods been the agent of denudation, we should have found ancient sea-beaches at the foot of the escarpments, and other signs of oceanic erosion. As a general rule, the wreck of the white chalk and its flints can only be traced to slight distances from the escarpments of the North and South Downs. Some exceptions occur, one of which was first pointed out to me in 1830, by the late Dr. Mantell. In this case the flints are seen near Barcombe, three miles from the nearest chalk, as indicated in the annexed section (fig. 331.). Even here it will be seen that the gravel reaches no farther than the Weald clay. But it is worthy of remark, that such depressions as that between Barcombe and Offham in this section, arising from the facility with which the argillaceous gault (No. 4. map. p. 273.) has been removed by water, are usually free from superficial detritus, although such valleys, situated at the foot of escarpments where there has been much waste, might have been supposed to be the natural receptacles of the wreck of the undermined cliffs. The question is therefore

Fig. 331.



Section from the north escarpment of the South Downs to Barcombe.

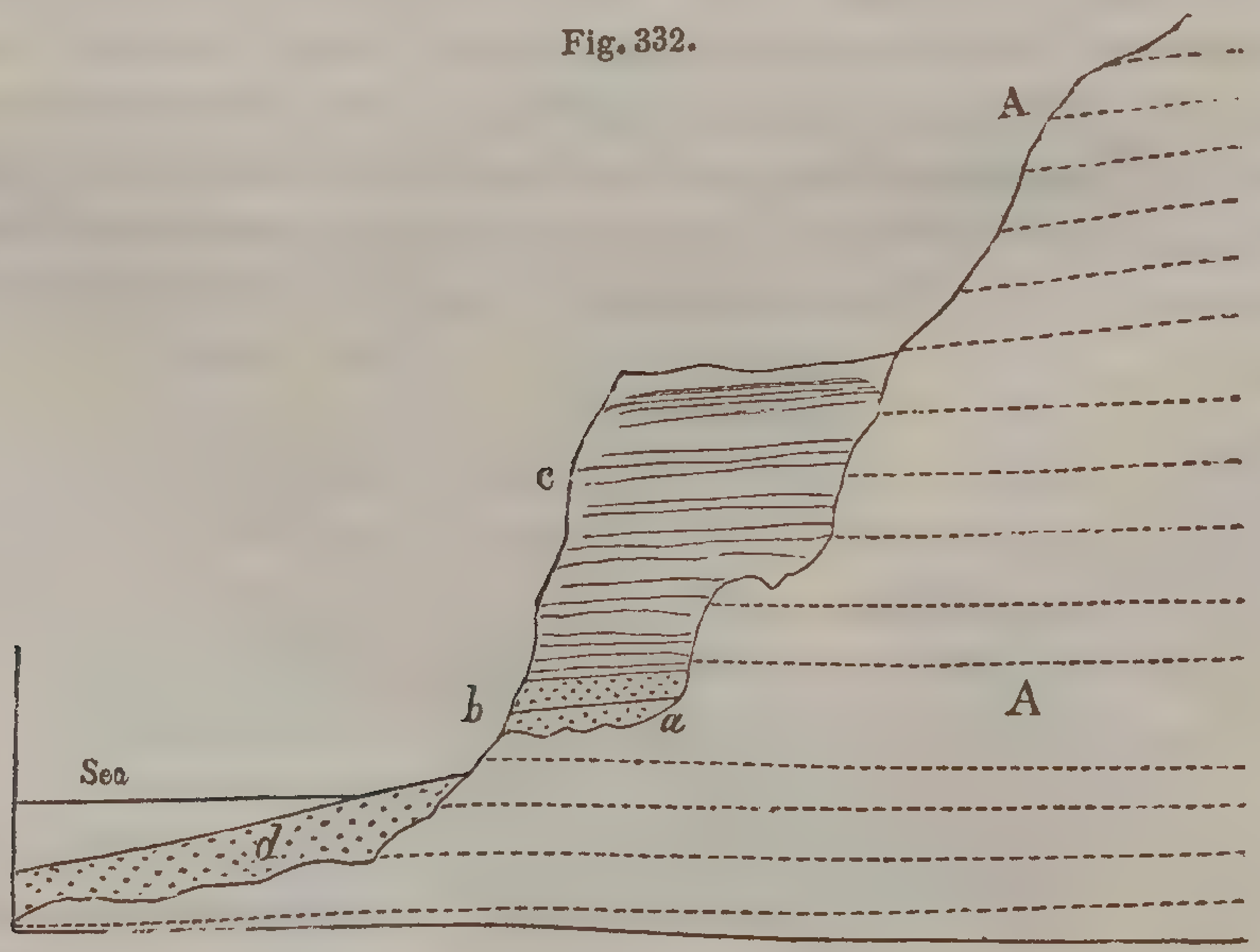
A. Layer of unrounded chalk-flints.
1. Gravel composed of partially rounded chalk-flints.
2. Chalk with and without flints.
3. Lowest chalk or chalk-marl (upper greensand wanting).
4. Gault. 5. Lower greensand. 6. Weald clay.

often put how these hollows could have been swept clean except by some extraordinary catastrophe.

The frequent angularity of the flints in the drift of Barcombe and other places is also insisted upon as another indication of denuding causes differing in kind and degree from any which man has witnessed. But all who have examined the gravel at the base of a chalk-cliff, in places where it is not peculiarly exposed to the continuous and violent action of the waves, are aware that the flints retain much angularity. This may be seen between the Old Harry rocks in Dorsetshire and Christchurch in Hampshire. Throughout the greater part of that line of coast the cliffs are formed of tertiary strata, capped by a dense covering of gravel formed of flints slightly abraded. As the waste of the cliffs is rapid the old materials are gradually changed for new ones on the beach; nevertheless we have here an example of angles being retained after two periods of attrition; first, where the gravel was spread originally over the Eocene deposits; and, secondly, after the Eocene sands and clays were undermined and the modern cliff formed.

Angular flint-breccia is not confined to the Weald, nor to the transverse gorges in the chalk, but extends along the neighbouring coast from Brighton to Rottingdean, where it was called by Dr. Mantell "the elephant-bed," because the bones of the mammoth abound in it with those of the horse and other mammalia. The following is a section of this formation as it appears in the Brighton cliff.*

Fig. 332.



A. Chalk with layers of flint dipping slightly to the south.
b. Ancient beach, consisting of fine sand, from one to four feet thick, covered by shingle from five to eight feet thick of pebbles of chalk-flint, granite, and other rocks, with broken shells of recent marine species, and bones of cetacea.
c. Elephant-bed, about fifty feet thick, consisting of layers of white chalk rubble, with broken chalk-flints, often more confusedly stratified than is represented in this drawing, in which deposit are found bones of ox, deer, horse, and mammoth.
d. Sand and shingle of modern beach.

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* See also Sir R. Murchison, Geol. Quart. Journ. vol. vii. p. 365.

To explain this section we must suppose that, after the excavation of the cliff A, the beach of sand and shingle *b* was formed by the long-continued action of the sea. The presence of *Littorina littorea* and other recent littoral shells determines the modern date of the accumulation. The overlying beds are composed of such calcareous rubble and flints, rudely stratified, as are often conspicuous in parts of the Norfolk coast, where they are associated with glacial drift, and were probably of contemporaneous origin. Similar flints and chalk-rubble have been recently traced by Sir Roderick Murchison to Folkestone and along the face of the cliffs at Dover, where the teeth of the fossil elephant have been detected.

Mr. Prestwich also has shown that at Sangatte, near Calais, on the coast exactly opposite Dover, a similar waterworn beach, with an incumbent mass of angular flint-breccia, is visible. I have myself visited this spot and found the deposit strictly analogous to that of Brighton. The fundamental ancient beach has been uplifted more than 10 feet above its original level. The flint-pebbles in it have evidently been rounded at the base of an ancient chalk-cliff, the course of which can still be traced inland, nearly parallel with the present shore, but with a space intervening between them of about one third of a mile in its greatest breadth. This space is occupied by a terrace, 100 feet in its greatest height, the component materials of which are too varied and complex to be described here. They are such as might, I conceive, have been heaped up above the sea-level in the delta of a river draining a region of white chalk. The delta may perhaps have been slowly subsiding while the strata accumulated. Some of the beds of chalk-rubble with broken flints appear to have had channels cut in them before the uppermost deposit of sand and loam was thrown down. The angularity of the flints, as Mr. Prestwich has suggested, may be owing to their having been previously shattered when in the body of the chalk itself; for we often see flints so fractured *in situ* in the chalk, especially when the latter has been much disturbed. The presence also in this Sangatte drift of large fragments of angular white chalk, some of them two feet in diameter, should be mentioned. They are confusedly mixed with smaller gravel and fine mud, for the most part devoid of stratification, and yet often too far from the old cliffs to have been a talus. I therefore suspect that the waters of the river and its tributaries were occasionally frozen over, and that during floods the carrying power of ice co-operated with that of water to transport fragile rocks and angular flints, leaving them unsorted when the ice melted, or not arranged according to size and weight as in deposits stratified by moving water. A climate like that now prevailing on the borders of the Baltic or in Canada might produce such effects long after the intense cold of the glacial epoch had passed away. The abundance of mammalia in countries where rivers are liable to be annually encumbered with ice, is a fact with which we are familiar in the northern hemisphere, and the frequency of fossil remains of quadrupeds in formations of glacial origin ought not to excite surprise. As to the angularity of the flints, it has been thought by some authorities to imply great violence in the removing power, especially in those cases where well-rounded pebbles washed out of Eocene strata are likewise found broken, sometimes with sharp edges and often with irregular pieces chipped out of them as if by a smart blow. Such fractured pebbles occur not unfrequently in the drift of the valley of the Thames. In explanation I may remark that, in the Blackheath and other Eocene shingle-beds, hard egg-shaped flint-pebbles may be found in such a state of decomposition as to break in the same manner on the application of a moderate blow, such as stones might encounter in the bed of a swollen river.

To conclude: It is a fact, not questioned by any geologist, that the area of the Weald once rose from beneath the sea after the origin of the chalk, that rock being a marine product, and now constituting dry land. Few will question, that part of the same area remained under water until after the origin of the Eocene deposits, because they also are marine, and reach to the edge of the chalk-downs. Whether, therefore, we do or do not admit the occurrence of reiterated submersions and emersions of land, the first of them as old as the Upper Cretaceous, the last perhaps of Newer Pliocene or even later date, we are at least compelled to grant that there was a time when, in the region under consideration, the waters of the sea retreated. The presence of land- and river-shells, and the bones of terrestrial quadrupeds in some of the gravel, loam, and flint-breccia of the Weald may indicate a fluviatile origin, but they can never disprove the prior occupation of the area by the sea. Heavy rains, the slow decomposition of rocks in the atmosphere, land-floods, and rivers (some of them larger than those now flowing in the same valleys) may have modified the surface and obliterated all signs of the antecedent presence of the sea. Littoral shells, once strewed over ancient shores, or buried in the sands of the beach, may have decomposed so as to make it impossible for us to assign an exact paleontological date to the older acts of denudation; but the removal of Chalk and Greensand from the central axis of the Weald, the leading inequalities of hill and dale, the long lines of escarpment, the longitudinal and transverse valleys, may still be mainly due to the power of the waves and currents of the sea, co-operating with that upheaval and subsidence and dislocation of rocks which all admit to have taken place.

In despair of solving the problem of the present geographical configuration and geological structure of the Weald by an appeal to ordinary causation, some geologists are fain to invoke the aid of imaginary "rushes of salt water" over the land, during the sudden upthrow of the bed of the sea, when the anticlinal axis of the Weald was formed. Others refer to vast bodies of fresh water breaking forth from subterranean reservoirs, when the rocks were riven by earthquake-shocks of intense violence. The singleness of the cause and the unity of the result are emphatically insisted upon: the catastrophe was abrupt, tumultuous, transient, and paroxysmal;

fragments of stone were swept along to great distances without time being allowed for attrition; alluvium was thrown down unstratified, and often in strange situations, on the flanks or on the summits of hills, while the lowest levels were left bare. The convulsion was felt simultaneously over so wide an area that all the individuals of certain species of quadrupeds were at once annihilated; yet the event was comparatively modern, for the species of testacea now living were already in existence.

This hypothesis is surely untenable and unnecessary. In the present chapter I have endeavoured to show how numerous have been the periods of geographical change, and how vast their duration. Evidence to this effect is afforded by the relative position of the chalk and overlying tertiary deposits; by the nature, character, and position of the tertiary strata; and by the overlying alluvia of the Weald and adjacent countries. As to the superficial detritus, its insignificance in volume, when compared to the missing rocks, should never be lost sight of. A mountain-mass of solid matter, hundreds of square miles in extent, and hundreds of yards in thickness, has been carried away bodily. To what distance it has been transported we know not, but certainly beyond the limits of the Weald. For achieving such a task, if we are to judge by analogy, all transient and sudden agency is hopelessly inadequate. There is one power alone which is competent to the task, namely, the mechanical force of water in motion, operating gradually, and for ages. We have seen in the 6th chapter that every stratified portion of the earth's crust is a monument of denudation on a grand scale, always effected slowly; for each superimposed stratum, however thin, has been successively and separately elaborated. Every attempt, therefore, to circumscribe the time in which any great amount of denudation, ancient or modern, has been accomplished, draws with it the gratuitous rejection of the only kind of machinery known to us which possesses the adequate power.

If, then, at every epoch, from the Cambrian to the Pliocene inclusive, voluminous masses of matter, such as are missing in the Weald, have been transferred from place to place, and always removed gradually, it seems extravagant to imagine an exception in the very region where we can prove the first and last acts of denudation to have been separated by so vast an interval of time. Here, might we say, if any where within the range of geological enquiry, we have time enough and without stint at our command.

CHAPTER XX.

JURASSIC GROUP.—PURBECK BEDS AND OOLITE.

The Purbeck beds a member of the Jurassic group—Subdivisions of that group—Physical geography of the Oolite in England and France—Upper Oolite—Purbeck beds—New fossil Mammifer found at Swanage—Dirt-bed or ancient soil—Fossils of the Purbeck beds—Portland stone and fossils—Lithographic stone of Solenhofen—Middle Oolite—Coral rag—Zoophytes—Nerinæan limestone—Diceras limestone—Oxford clay, Ammonites and Belemnites—Lower Oolite, Crinoideans—Great Oolite and Bradford clay—Stonesfield slate—Fossil mammalia, placental and marsupial—Resemblance to an Australian fauna—Northamptonshire slates—Yorkshire Oolitic coal-field—Brora coal—Fuller's earth—Inferior Oolite and fossils.

IMMEDIATELY below the Hastings Sands (the inferior member of the Wealden, as defined in the 18th chapter), we find in Dorsetshire another remarkable freshwater formation, called *the Purbeck*, because it was first studied in the sea-cliffs of the peninsula of Purbeck in Dorsetshire. These beds were formerly grouped with the Wealden, but some organic remains recently discovered in certain intercalated marine beds show that the Purbeck series has a close affinity to the Oolitic group, of which it may be considered as the newest or uppermost member.

In England generally, and in the greater part of Europe, both the Wealden and Purbeck beds are wanting, and the marine cretaceous group is followed immediately, in the descending order, by another series called the Jurassic. In this term, the formations commonly designated as "the Oolite and Lias" are included, both being found in the Jura Mountains. The Oolite was so named because in the countries where it was first examined, the limestones belonging to it had an oolitic structure (see p. 12.). These rocks occupy in England a zone which is nearly 30 miles in average breadth, and extends across the island, from Yorkshire in the north-east, to Dorsetshire in the south-west. Their mineral characters are not uniform throughout this region; but the following are the names of the principal subdivisions observed in the central and south-eastern parts of England:—

OOLITE.

Upper	*a.* Purbeck beds.
	b. Portland stone and sand.
	c. Kimmeridge clay.
Middle	*d.* Coral rag.
	e. Oxford clay.
Lower	*f.* Cornbrash and Forest marble.
	g. Great Oolite and Stonesfield slate.
	h. Fuller's earth.
	i. Inferior Oolite.

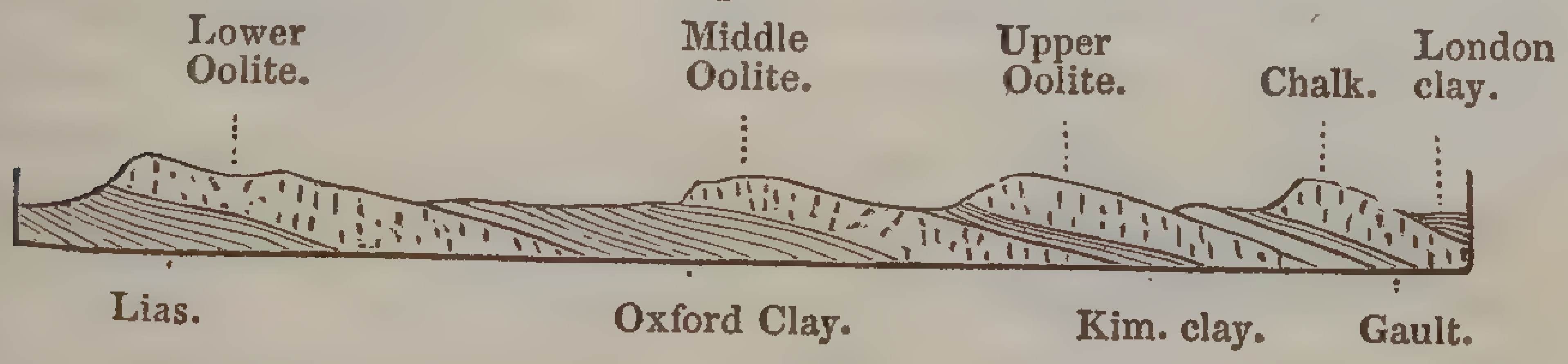
The Lias then succeeds to the Inferior Oolite.

The Upper oolitic system of the above table has usually the Kimmeridge clay for its base; the Middle oolitic system, the Oxford clay. The Lower system reposes on the Lias, an argillo-calcareous formation, which some include in the Lower Oolite, but which will be treated of separately in the next chapter. Many of these subdivisions are distinguished by peculiar organic remains; and, though varying in thickness, may be traced in certain directions for great distances, especially if we compare the part of England to which the above-mentioned type refers with the north-east of France and the Jura mountains adjoining. In that country, distant above 400 geographical miles, the analogy to the accepted English type, notwithstanding the thinness or occasional absence of the clays, is more perfect than in Yorkshire or Normandy.

Physical geography. — The alternation, on a grand scale, of distinct formations of clay and limestone has caused the oolitic and liassic series to give rise to some marked features in the physical outline of parts of England and France. Wide valleys can usually be traced throughout the long bands of country where the argillaceous strata crop out; and between these valleys the limestones are observed, composing ranges of hills or more elevated grounds. These ranges terminate abruptly on the side on which the several clays rise up from beneath the calcareous strata.

The annexed cut will give the reader an idea of the configuration of the surface now alluded to, such as may be seen in passing from London to Cheltenham, or in other parallel lines, from east to west, in the southern part of England. It has been necessary, however, in this drawing, greatly to exaggerate the inclination of the beds, and the height of the several formations, as compared to their horizontal extent. It will be remarked, that the lines of cliff, or escarpment, face towards the west in the great calcareous eminences formed by the Chalk and the Upper, Middle, and Lower Oolites; and at the base of which we have respectively the Gault, Kimmeridge clay, Oxford clay, and Lias. This last forms, generally, a broad vale at the foot of the escarpment of inferior oolite, but where it acquires considerable thickness, and contains solid beds of marlstone, it occupies the lower part of the escarpment.

Fig. 333.



The external outline of the country which the geologist observes in travelling eastward from Paris to Metz is precisely analogous, and is caused by a similar succession of rocks intervening between the tertiary strata and the Lias; with this difference, however, that the escarpments of Chalk, Upper, Middle, and Lower Oolites face towards the east instead of the west.

The Chalk crops out from beneath the tertiary sands and clays of the Paris basin, near Epernay, and the Gault from beneath the Chalk and Upper Greensand at Clermont-en-Argonne; and passing from this place by Verdun and Etain to Metz, we find two limestone ranges, with intervening vales of clay, precisely resembling those of southern and central England, until we reach the great plain of Lias at the base of the Inferior Oolite at Metz.

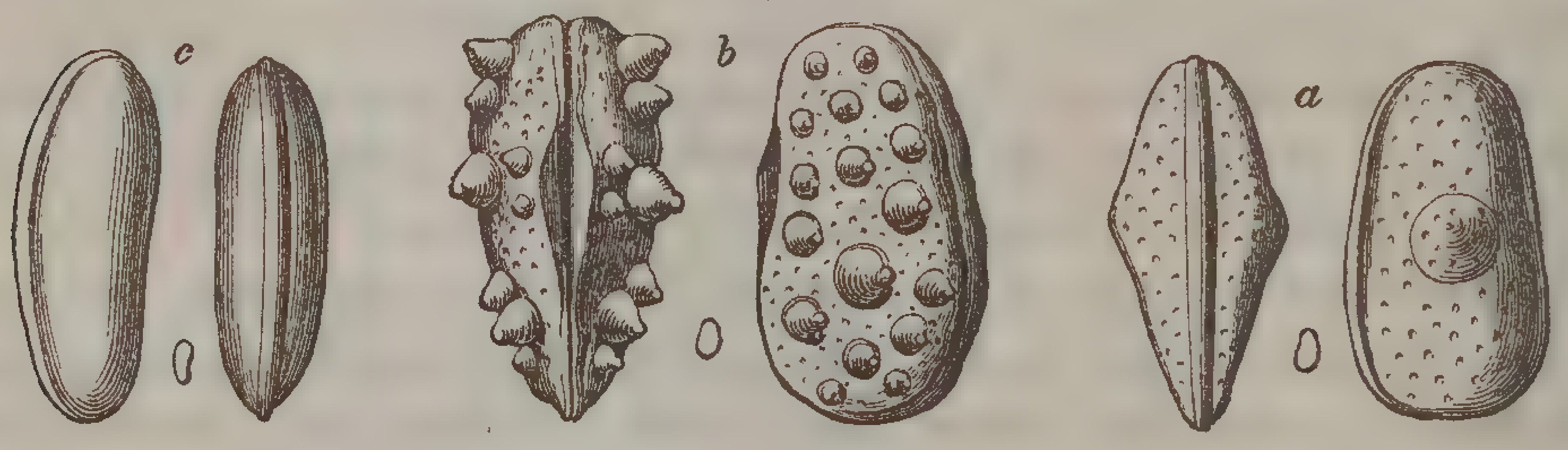
It is evident, therefore, that the denuding causes have acted similarly over an area several hundred miles in diameter, sweeping away the softer clays more extensively than the limestones, and undermining these last so as to cause them to form steep cliffs wherever the harder calcareous rock was based upon a more yielding and destructible clay.

UPPER OOLITE.

Purbeck beds (*a.* Tab. p. 292.).— These strata, which we class as the uppermost member of the Oolite, are of limited geographical extent in Europe, as already stated, but they acquire importance, when we consider the succession of three distinct sets of fossil remains which they contain. Such repeated changes in organic life must have reference to the history of a vast lapse of ages. The Purbeck beds are finely exposed to view in Durdlestone Bay, near Swanage, Dorsetshire, and at Lulworth Cove and the neighbouring bays between Weymouth and Swanage. At Meup's Bay, in particular, Prof. E. Forbes examined minutely in 1850 the organic remains of this group, displayed in a continuous, sea-cliff section; and he added largely to the information previously supplied in the works of Messrs. Webster, Fitton, De la Beche, Buckland, and Mantell. It appears from these researches that the Upper, Middle, and Lower Purbecks are each marked by peculiar species of organic remains, these again being different, so far as a comparison has yet been instituted, from the fossils of the overlying Hastings Sands and Weald Clay.*

Upper Purbeck. — The highest of the three divisions is purely freshwater, the strata, about 50 feet in thickness, containing shells of the genera *Paludina*, *Physa*, *Limnæus*, *Planorbis*, *Valvata*, *Cyclas*, and *Unio*, with *Cyprides* and fish. All the species seem peculiar, and among these the *Cyprides* are very abundant and characteristic. (See figs. 334. *a*, *b*, *c*.)

Fig. 334.



Cyprides from the Upper Purbecks.
a. Cypris gibbosa, E. Forbes. *b. Cypris tuberculata*, E. Forbes. *c. Cypris leguminella*, E. Forbes.

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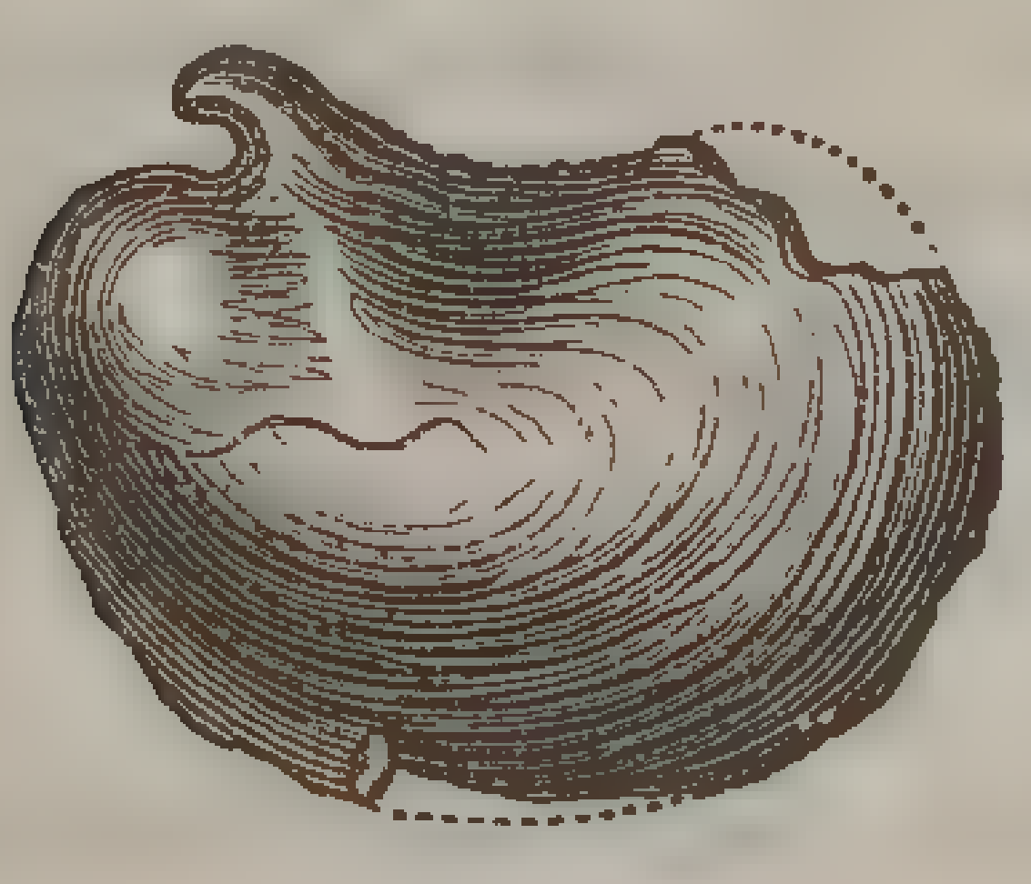
* "On the Dorsetshire Purbecks," by Prof. E. Forbes, Brit. Assoc. Edinb. 1850.

The stone called "Purbeck marble," formerly much used in ornamental architecture in the old English cathedrals of the southern counties, is exclusively procured from this division.

Middle Purbeck.—Next in succession is the Middle Purbeck, about 30 feet thick, the uppermost part of which consists of freshwater limestone, with cyprides, turtles, and fish, of different species from those in the preceding strata. Below the limestone are brackish-water beds full of *Cyrena*, and traversed by bands abounding in *Corbula* and *Melania*. These are based on a purely marine deposit, with *Pecten*, *Modiola*, *Avicula*, *Thracia*, all undescribed shells. Below this, again, come limestones and shales, partly of brackish and partly of freshwater origin, in which many fish, especially species of *Lepidotus* and *Microdon radiatus*, are found, and a crocodilian reptile named *Macrorhyncus*. Among the mollusks, a remarkable ribbed *Melania*, of the section *Chilira*, occurs.

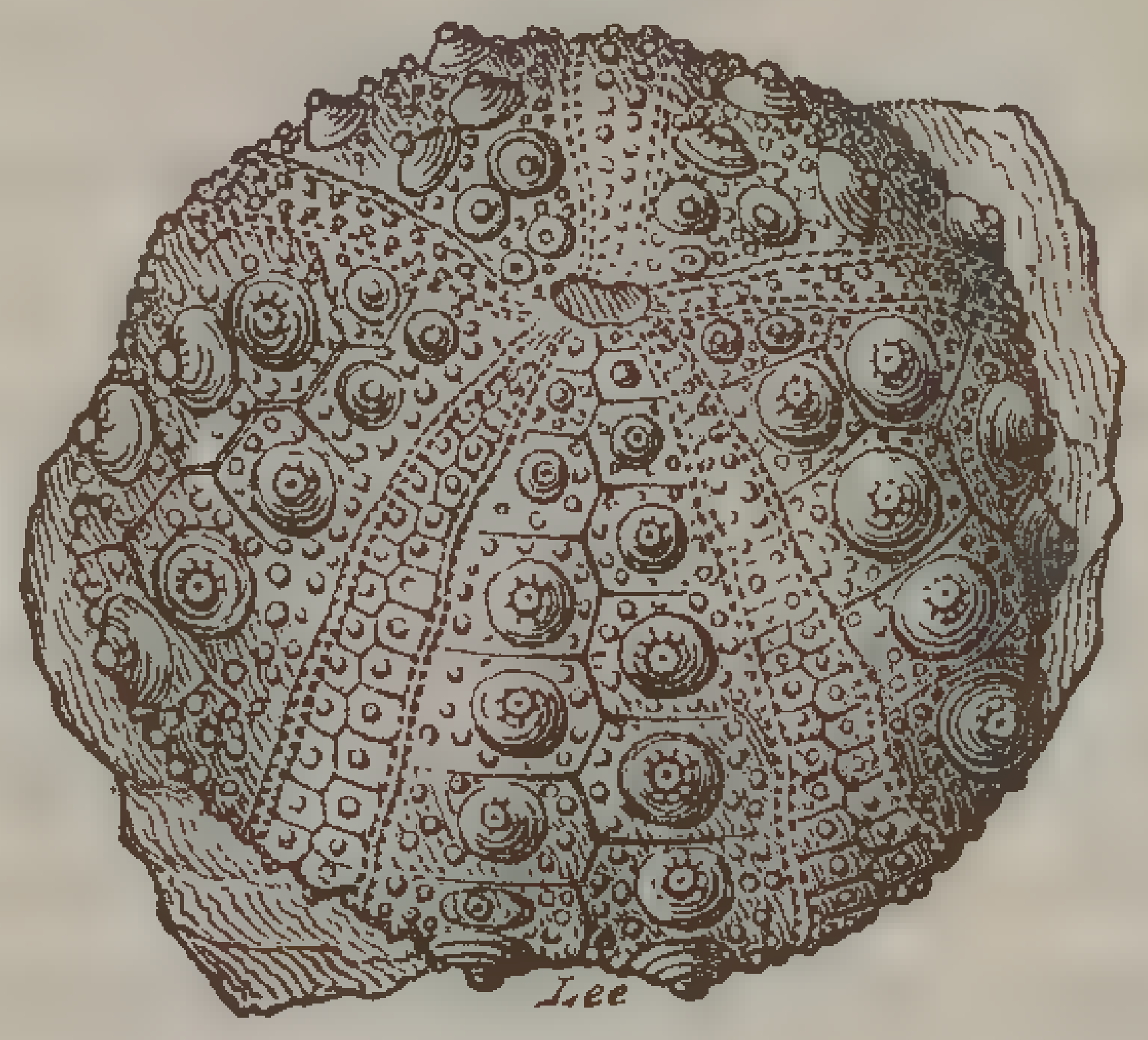
Immediately below is the great and conspicuous stratum, 12 feet thick, long familiar to geologists under the local name of "Cinder-bed," formed of a vast accumulation of shells of *Ostrea distorta* (fig. 335.). In the uppermost part of this bed Prof. Forbes discovered the first echinoderm (fig. 336.) as yet known in the Purbeck series, a species of *Hemicidaris*, a genus characteristic of the Oolitic period, and scarcely, if at all, distinguishable from a previously known oolitic species. It was accompanied by a species of *Perna*.

Fig. 335.



Ostrea distorta.
Cinder-bed, Middle Purbeck.

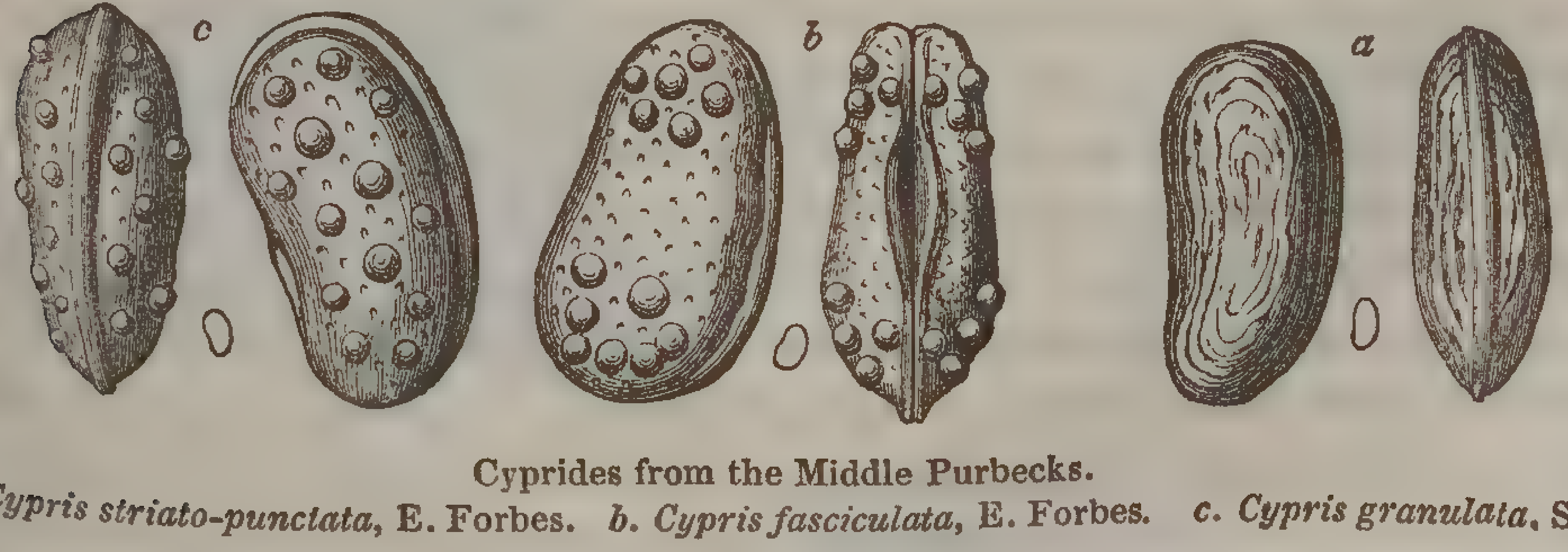
Fig. 336.



Hemicidaris Purbeckensis, E. Forbes.
Middle Purbeck.

Below the Cinder-bed freshwater strata are again seen, filled in many places with species of *Cypris* (fig. 337. *a*, *b*, *c*), and with *Valvata*,

Fig. 337.



Cyprides from the Middle Purbecks.
a. Cypris striato-punctata, E. Forbes. *b. Cypris fasciculata*, E. Forbes. *c. Cypris granulata*, Sow.

Paludina, *Planorbis*, *Limnæus*, *Physa* (fig. 338.), and *Cyclas*, all different from any occurring higher in the series. It will be seen

Fig. 338.

Physa Bristovii, E. Forbes. Middle Purbeck.

that *Cypris fasciculata* (fig. 337. *b*) has tubercles at the end only of each valve, a character by which it can be immediately recognized. In fact, these minute crustaceans, almost as frequent in some of the shales as plates of mica in a micaceous sandstone, enable geologists at once to identify the Middle Purbeck in places far from the Dorsetshire cliffs, as for example, in the Vale of Wardour, in Wiltshire. Thick siliceous beds of chert occur in the Middle Purbeck filled with mollusca and cyprides of the genera already enumerated, in a beautiful state of preservation, often converted into chalcedony. Among these Prof. Forbes met with gyrogonites (the spore vessels of *Charæ*), plants never until 1851 discovered in rocks older than Eocene. In a bed of this series, about 20 feet below the "Cinder," Mr. W. R. Brodie has lately found (1854), in Durdlestone Bay, portions of several small jaws with teeth, which Prof. Owen, after clearing away the matrix, recognized as belonging to a small mammifer of the insectivorous class. The teeth with pointed cusps resemble in some degree those of the Cape Mole (*Chrysochlora aurea*); but the number of the molar teeth (at least ten in each ramus of the lower jaw) accords with that in the extinct Thylacotherium of the Stonesfield Oolite (see below, Chap. XX.). This newly found quadruped, therefore, seems to have been more closely allied in its dentition to the Thylacotherium than to any existing insectivorous type. As in Thylacotherium, the angular process of the jaw is not bent inwards, an osteological peculiarity confined to the marsupial tribes (see Chap. XX.), and Prof. Owen therefore refers the *Spalacotherium* to the placental or ordinary class of monodelphous mammalia.

In a former edition of this work (1852), after alluding to the discovery of numerous insects and air-breathing mollusca in the "Purbeck," I remarked that, although no mammalia had then been found, "it was too soon to infer their non-existence on mere negative evidence." The scarcity of the remains of warm-blooded quadrupeds in Oolitic rocks, and the fact of none having yet been met with in deposits of the Cretaceous era, may imply that there were few mammalia then living, and their limited numbers may possibly have some connection with the enormous development of reptile life in all Secondary periods, as compared to Tertiary or Recent times. If so, the phenomenon has at least no relation to an incipient or immature condition of the planet, as some have imagined, for, so far from being characteristic of primary or even older secondary times, it belongs to the Maestricht chalk, the newest subdivision of the cretaceous series, and that too in a manner even more marked than in the older oolitic rocks. Nevertheless in the present imperfect state of our information respecting the land-animals of the Cretaceous and Jurassic periods, exclusively derived from marine and flaviatile strata, and our total ignorance of the deposits formed in lakes and caverns at the same date, it would be premature to attempt to generalize on the nature of so ancient a terrestrial fauna.

Beneath the freshwater strata last described, a very thin band of greenish shales, with marine shells and impressions of leaves, like those of a large *Zostera*, succeeds, forming the base of the Middle Purbeck.

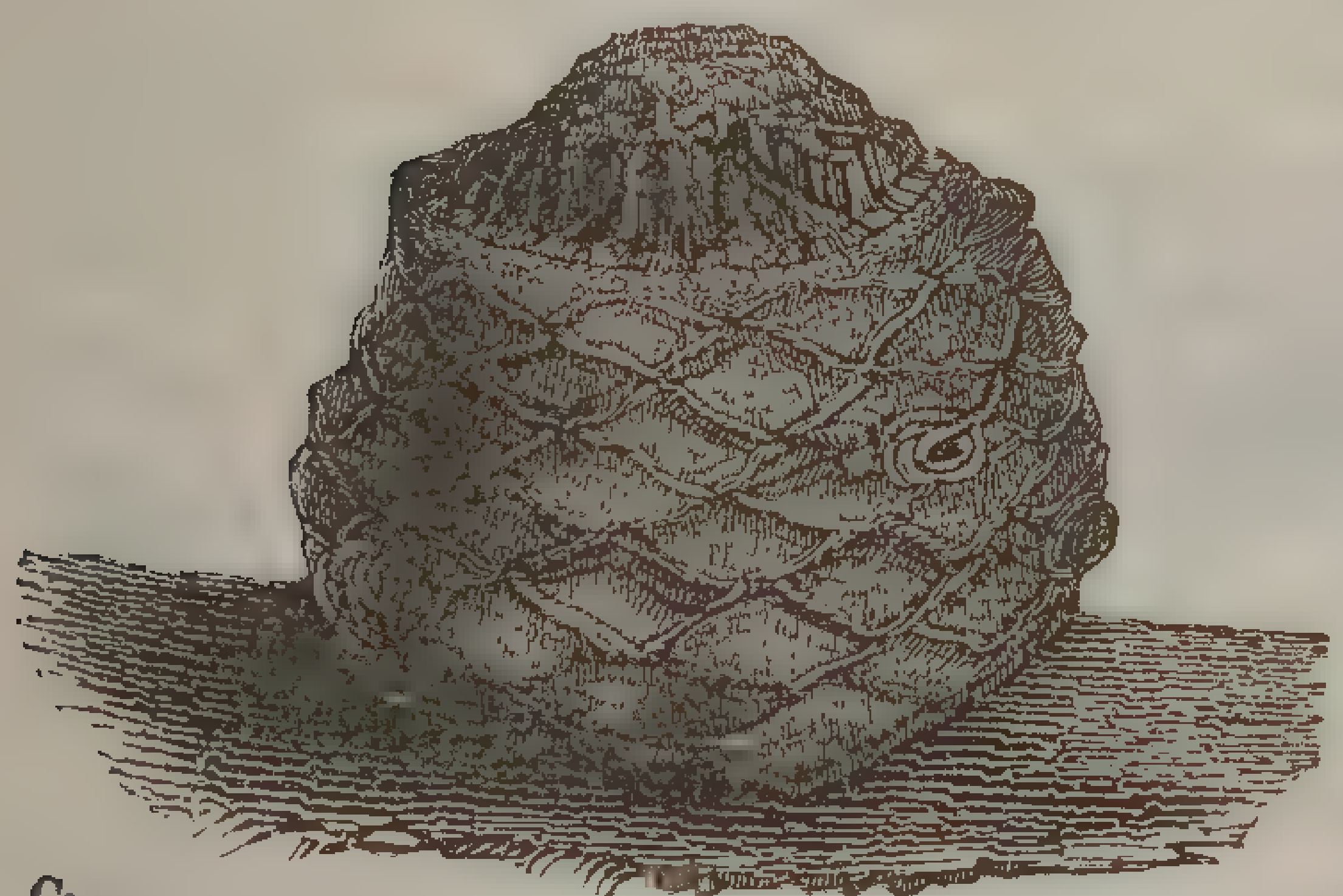
Lower Purbeck.—Beneath the thin marine band above mentioned, purely freshwater marls occur, containing species of *Cypris* (fig. 339. *a*, *b*), *Valvata*, and *Limnæus*, different from those of the Middle Purbeck. This is the beginning of the inferior division, which is about 80 feet thick. Below the marls are seen more than 30 feet of brackish-water beds, at Meup's Bay, abounding in a species of *Serpula*, allied to, if not identical with, *Serpula coacervites*, found in beds of the same age in Hanover. There are also shells of the genus *Rissoa* (of the subgenus *Hydrobia*), and a little *Cardium* of the subgenus *Protocardium*, in the same beds, together with *Cypris*. Some of the cypris-bearing shales are strangely contorted and broken up, at the west end of the Isle of Purbeck. The great dirt-bed or vegetable soil containing the roots and stools of *Cycadeæ*, which I shall presently describe, underlies these marls, and rests upon the lowest freshwater limestone, a rock about 8 feet thick, containing *Cyclas*, *Valvata*, and *Limnæus*, of the same species as those of the uppermost part of the Lower Purbeck, or above the dirt-bed. The freshwater limestone in its turn rests upon the top beds of the Portland stone, which, although it contains purely marine remains, often consists of a rock quite homogeneous in mineral character with the Lowest Purbeck limestone.*

Fig. 339.

Cyprides from the Lower Purbecks.
a. Cypris Purbeckensis, E. Forbes. *b. Cypris punctata*, E. Forbes.

The most remarkable of all the varied succession of beds enumerated in the above list, is that called by the quarrymen "the dirt," or "black dirt," which was evidently an ancient vegetable soil. It is from 12 to 18 inches thick, is of a dark brown or black colour, and contains a large proportion of earthy lignite. Through it are dispersed rounded fragments of stone, from 3 to 9 inches in diameter, in such numbers that it almost deserves the name of gravel. Many silicified trunks of coniferous trees, and the re-

Fig. 340.



Cycadeoidea (Mantellia) megalophylla, Buckland.

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* Weston, Geol. Q. J., vol. viii. p. 117.

mains of plants allied to *Zamia* and *Cycas*, are buried in this dirt-bed (see figure of fossil species, fig. 340., and of living *Zamia*, fig. 341.)

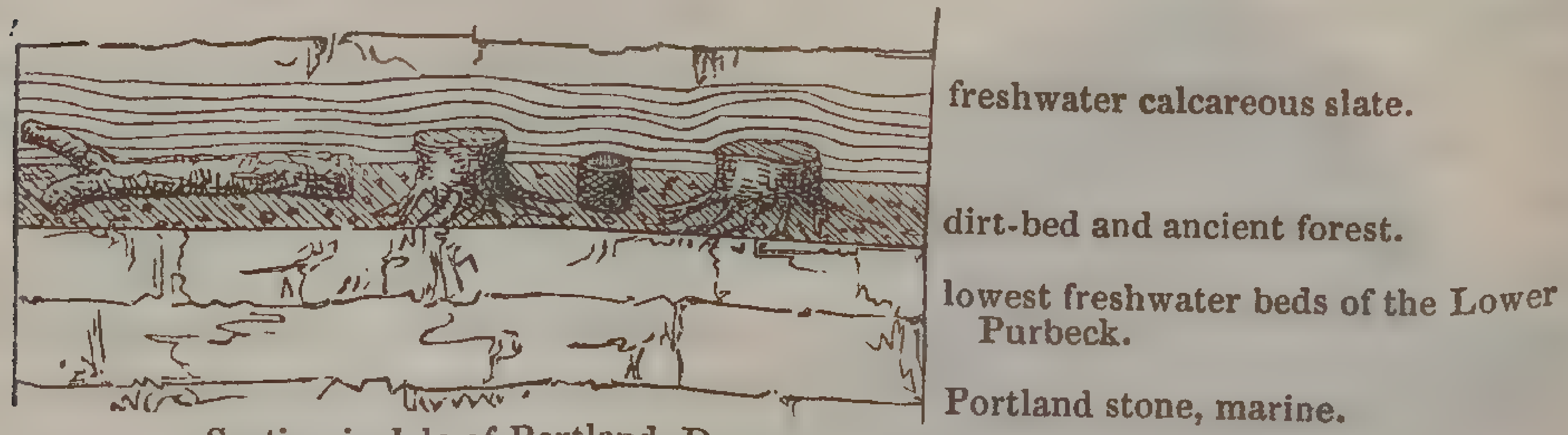
Fig. 341.

Zamia spiralis. Southern Australia.

These plants must have become fossil on the spots where they grew. The stumps of the trees stand erect for a height of from 1 to 3 feet, and even in one instance to 6 feet, with their roots attached to the soil at about the same distances from one another as the trees in a modern forest.* The carbonaceous matter is most abundant immediately around the stumps, and round the remains of fossil *Cycadeæ*.†

Besides the upright stumps above mentioned, the dirt-bed contains the stems of silicified trees laid prostrate. These are partly sunk into the black earth, and partly enveloped by a calcareous slate which covers the dirt-bed. The fragments of the prostrate trees are rarely more than 3 or 4 feet in length; but by joining many of them together, trunks have been restored, having a length from the root to the branches of from 20 to 23 feet, the stems being undivided for 17 or 20 feet, and then forked. The diameter of these near the roots is about 1 foot. Root-shaped cavities were observed by Professor Henslow to descend from the bottom of the dirt-bed into the subjacent freshwater stone, which, though now solid, must have been in a soft and penetrable state when the trees grew.‡

Fig. 342.



Section in Isle of Portland, Dorset. (Buckland and De la Beche.)

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* Mr. Webster first noticed the erect position of the trees and described the Dirt-bed.

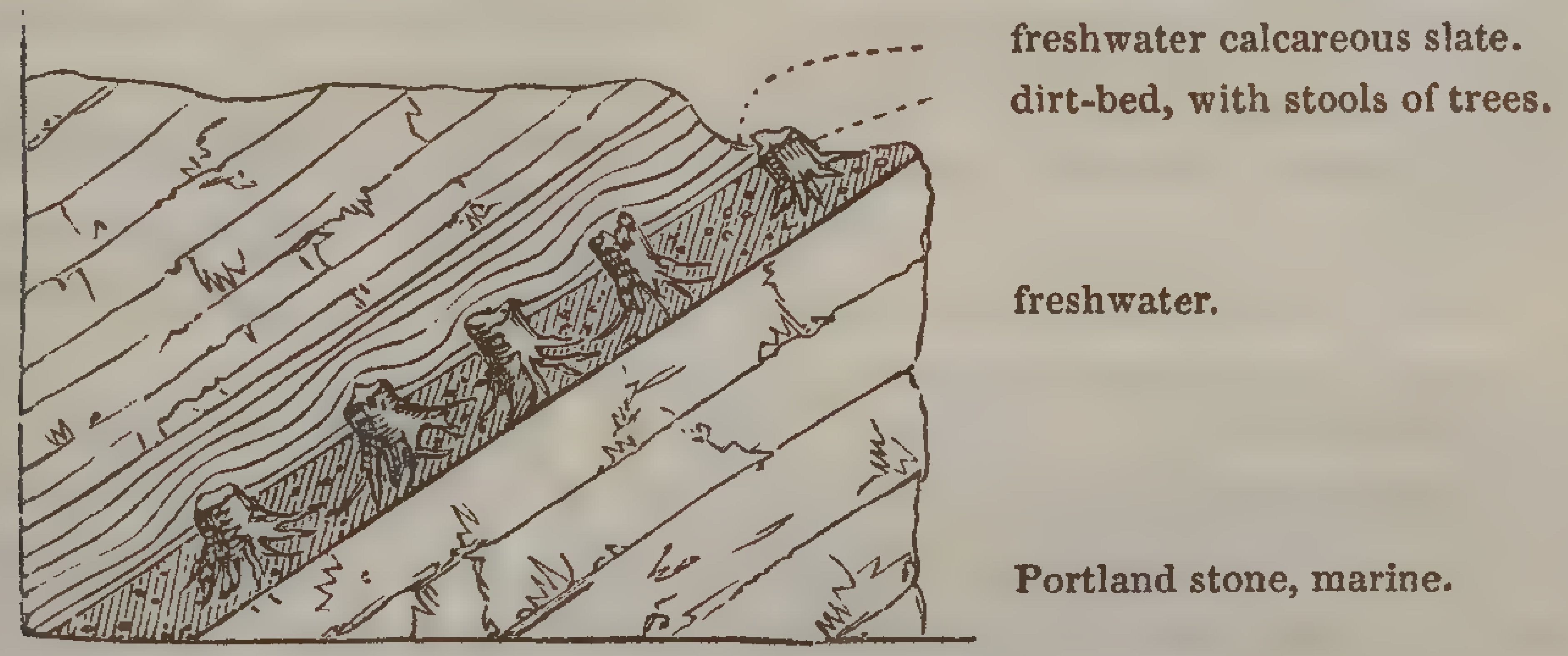
† Fitton, Geol. Trans., Second Series, vol. iv. pp. 220, 221.

‡ Buckland and De la Beche, Geol. Trans., Second Series, vol. iv. p. 16. Prof. Forbes has ascertained that the subjacent rock is a freshwater limestone, and not a portion of the Portland oolite, as was previously imagined.

The thin layers of calcareous slate (fig. 342.) were evidently deposited tranquilly, and would have been horizontal but for the protrusion of the stumps of the trees, around the top of each of which they form hemispherical concretions.

The dirt-bed is by no means confined to the island of Portland, where it has been most carefully studied, but is seen in the same relative position in the cliffs east of Lulworth Cove, in Dorsetshire, where, as the strata have been disturbed, and are now inclined at an angle of 45°, the stumps of the trees are also inclined at the same angle in an opposite direction—a beautiful illustration of a change in the position of beds originally horizontal (see fig. 343.). Traces of the dirt-bed have also been observed by Mr. Fisher, at Ridgway; by Dr. Buckland, about two miles north of Thame, in Oxfordshire; and by Dr. Fitton, in the cliffs in the Boulonnois, on the French coast; but, as might be expected, this freshwater deposit is of limited extent when compared to most marine formations.

Fig. 343.



Section in cliff east of Lulworth Cove. (Buckland and De la Beche.)

From the facts above described, we may infer, first, that those beds of the upper Oolite, called "the Portland," which are full of marine shells, were overspread with fluviatile mud, which became dry land, and covered by a forest, throughout a portion of the space now occupied by the south of England, the climate being such as to admit the growth of the *Zamia* and *Cycas*. 2dly. This land at length sank down and was submerged with its forests beneath a body of fresh water, from which sediment was thrown down enveloping fluviatile shells. 3dly. The regular and uniform preservation of this thin bed of black earth over a distance of many miles, shows that the change from dry land to the state of a freshwater lake or estuary, was not accompanied by any violent denudation, or rush of water, since the loose black earth, together with the trees which lay prostrate on its surface, must inevitably have been swept away had any such violent catastrophe taken place.

The dirt-bed has been described above in its most simple form, but in some sections the appearances are more complicated. The forest of the dirt-bed was not everywhere the first vegetation which grew in this region. Two other beds of carbonaceous clay, one of them containing *Cycadeæ*, in an upright position, have been found below it, and one above it, which implies other oscillations in the level of the same ground, and its alternate occupation by land and water more than once.

Table showing the changes of medium in which the strata were formed, from the Portland Stone up to the Lower Greensand inclusive, in the south-east of England (beginning with the lowest).

1.	Marine	Portland Stone.
2.	Freshwater	Lower Purbeck.
	Land	
	Freshwater	
	Land	
	Freshwater	
	Land (Dirt-bed)	
	Freshwater	
	Land	
	Brackish	
	Freshwater	
3.	Marine	Middle Purbeck.
	Freshwater	
	Marine	
	Brackish	
	Marine	
	Brackish	
	Freshwater	
4.	Freshwater	Upper Purbeck.
5.	Freshwater	Hastings Sands.
	Brackish	
	Freshwater	
6.	Freshwater	Wealden Clay.
7.	Marine	Lower Greensand.

The annexed tabular view will enable the reader to take in at a glance the successive changes from sea to river, and from river to sea, or from these again to a state of land, which have occurred in this part of England between the Oolitic and Cretaceous periods. That there have been at least four changes in the species of testacea during the deposition of the Wealden and Purbeck beds, seems to follow from the observations recently made by Prof. Forbes, so that, should we hereafter find the signs of many more alternate occupations of the same area by different elements, it is no more than we might expect. Even during a small part of a zoological period, not sufficient to allow time for many species to die out, we find that the same area has been laid dry, and then submerged, and then again laid dry, as in the deltas of the Po and Ganges, the history of which has been brought to light by Artesian borings.* We also know that similar revolutions have occurred within the present century (1819) in the delta of the Indus in Cutch†, where land has been laid permanently under the waters both of the river and sea, without its soil or shrubs having been swept away. Even, independently of any vertical movements of the ground, we see in the principal deltas, such as that of the Mississippi, that the sea extends its salt waters annually for many months over considerable spaces which, at other seasons, are occupied by the river during its inundations.

It will be observed that the division of the Purbecks into upper, middle, and lower has been made by Prof. Forbes, strictly on the principle of the entire distinctness of the species of organic remains which they include. The lines of demarcation are not lines of disturbance, nor indicated by any striking physical characters or mineral changes. The features which attract the eye in the Purbecks, such as the dirt-beds, the dislocated strata at Lulworth, and the Cinder-

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* See Principles of Geol. 9th ed. pp. 255. 275.

† Ibid. p. 460.

bed, do not indicate any breaks in the distribution of organized beings. "The causes which led to a complete change of life three times during the deposition of the freshwater and brackish strata must," says this naturalist, "be sought for, not simply in either a rapid or a sudden change of their area into land or sea, but in the great lapse of time which intervened between the epochs of deposition at certain periods during their formation."

Each dirt-bed may, no doubt, be the memorial of many thousand years or centuries, because we find that 2 or 3 feet of vegetable soil is the only monument which many a tropical forest has left of its existence ever since the ground on which it now stands was first covered with its shade. Yet, even if we imagine the fossil soils of the Lower Purbeck to represent as many ages, we need not expect on that account to find them constituting the lines of separation between successive strata characterized by different zoological types. The preservation of a layer of vegetable soil, when in the act of being submerged, must be regarded as a rare exception to a general rule. It is of so perishable a nature, that it must usually be carried away by the denuding waves or currents of the sea or by a river; and many Purbeck dirt-beds were probably formed in succession, and annihilated, besides those few which now remain.

The plants of the Purbeck beds, so far as our knowledge extends at present, consist chiefly of Ferns, Coniferæ (fig. 344.), and Cycadeæ (fig. 340.), without any exogens; the whole more allied to the Oolitic than to the Cretaceous vegetation. The vertebrate and invertebrate animals indicate, like the plants, a somewhat nearer relationship to the Oolitic than to the cretaceous period. Mr. Brodie has found the remains of beetles and several insects of the homopterous and trichopterous orders, some of which now live on plants, while others are of such forms as hover over the surface of our present rivers.

Fig. 344.

Cone of a pine from the Isle of Purbeck. (Fitton.)

Portland Stone and Sand (*b*. Tab. p. 292.).—The Portland stone has already been mentioned as forming in Dorsetshire the foundation on which the freshwater limestone of the Lower Purbeck reposes (see p. 297.). It supplies the well-known building-stone of which St. Paul's and so many of the principal edifices of London are constructed. This upper member rests on a dense bed of sand, called the Portland sand, containing for the most part similar marine fossils, below which is the Kimmeridge clay. In England these Upper Oolite formations are almost wholly confined to the southern counties. Corals are rare in them, although one species is found plentifully at Tisbury, Wiltshire, in the Portland sand, converted into flint and chert, the original calcareous matter being replaced by silex (fig. 345.).

The Kimmeridge clay consists, in great part, of a bituminous shale, sometimes forming an impure coal, several hundred feet in thickness. In some places in Wiltshire it much resembles peat; and the bitumi-

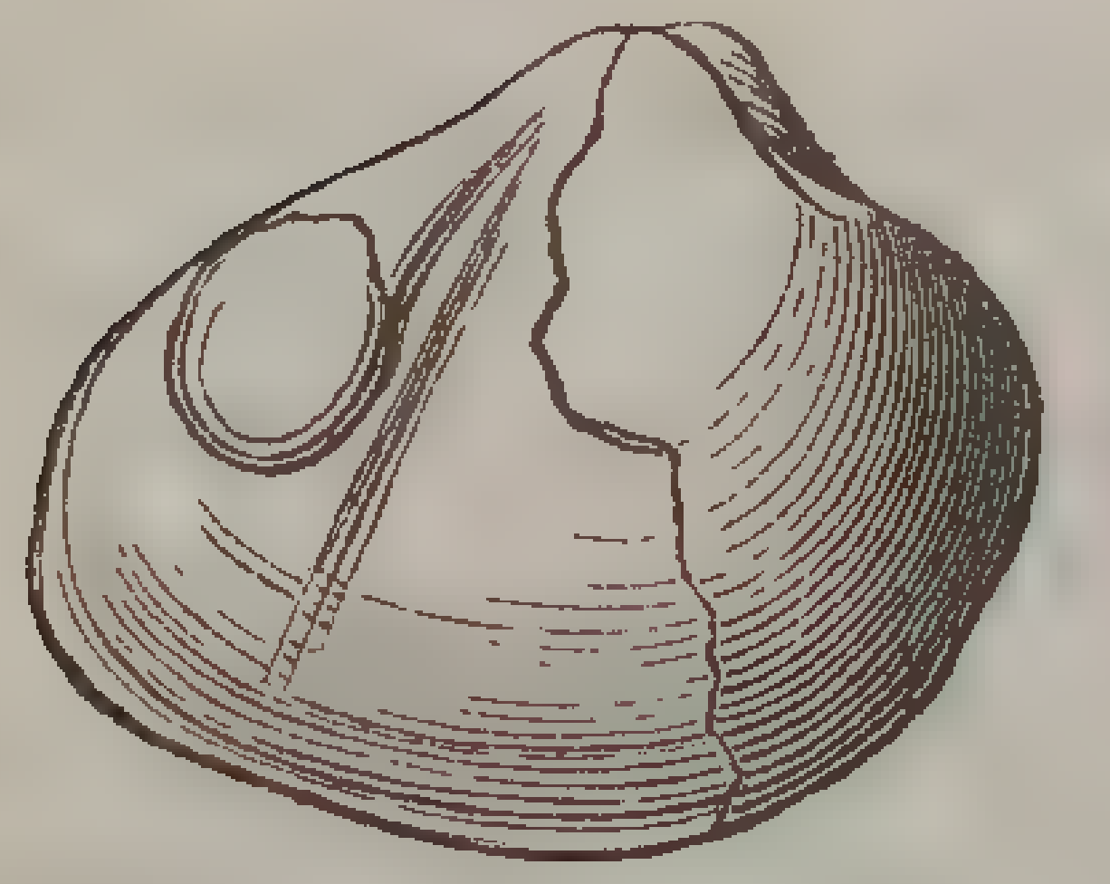
Fig. 345.

Isastræa oblonga, M. Edw. and J. Haime.
As seen on a polished slab of chert from
the Portland Sand, Tisbury.

Fig. 346.

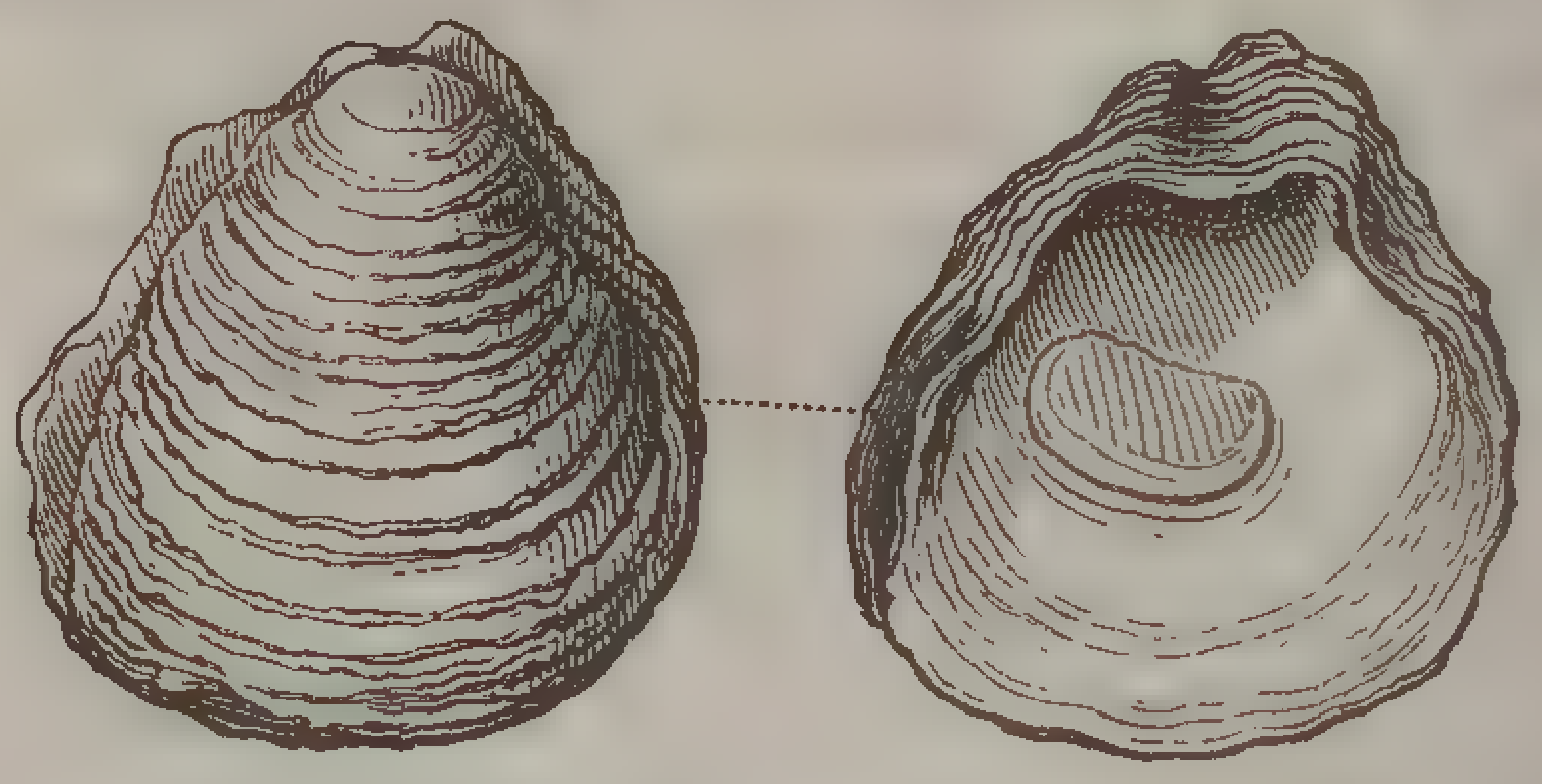
Trigonia gibbosa. ½ nat. size.
a. the hinge.
Portland Stone, Tisbury

Fig. 347.



Cardium dissimile. ¼ nat. size.
Portland Stone.

Fig. 348.

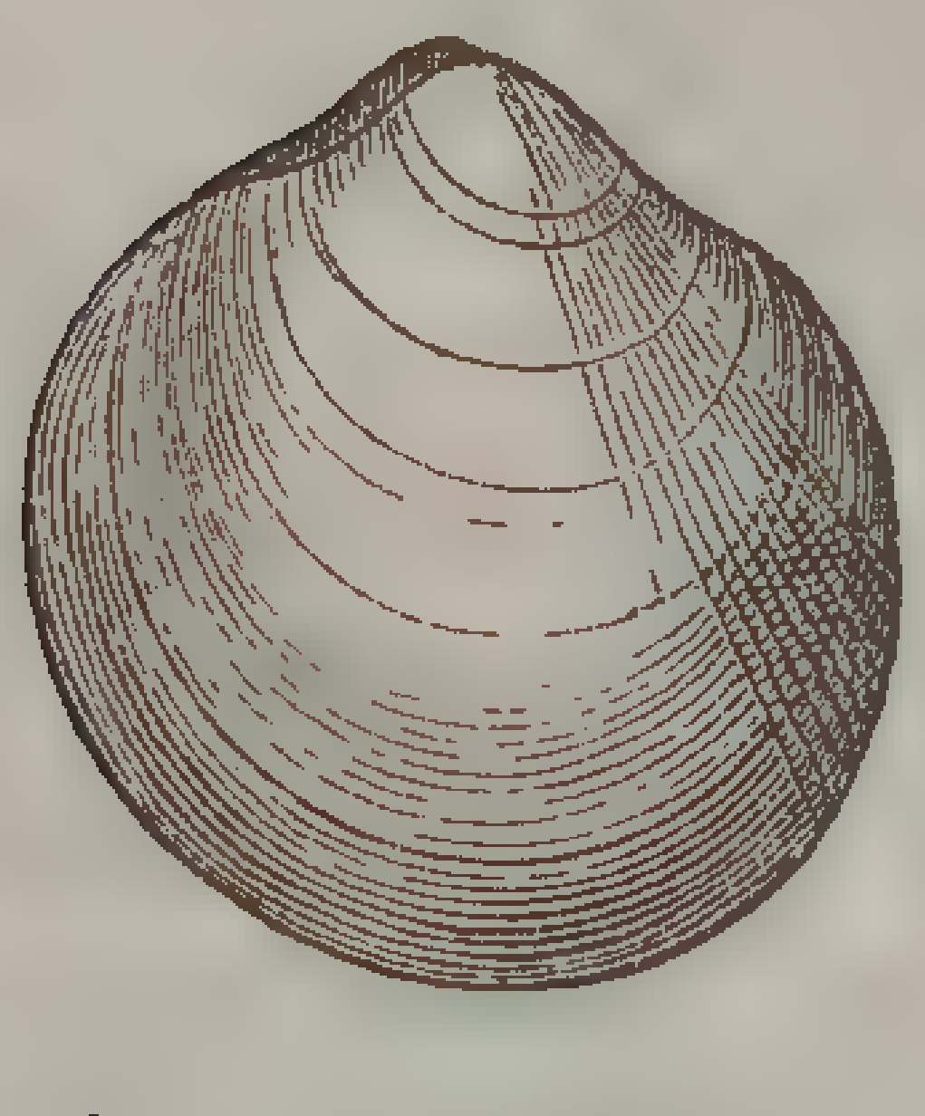


Ostrea expansa.
Portland Sand.

nous matter may have been, in part at least, derived from the decomposition of vegetables. But as impressions of plants are rare in these shales, which contain ammonites, oysters, and other marine shells, the bitumen may perhaps be of animal origin.

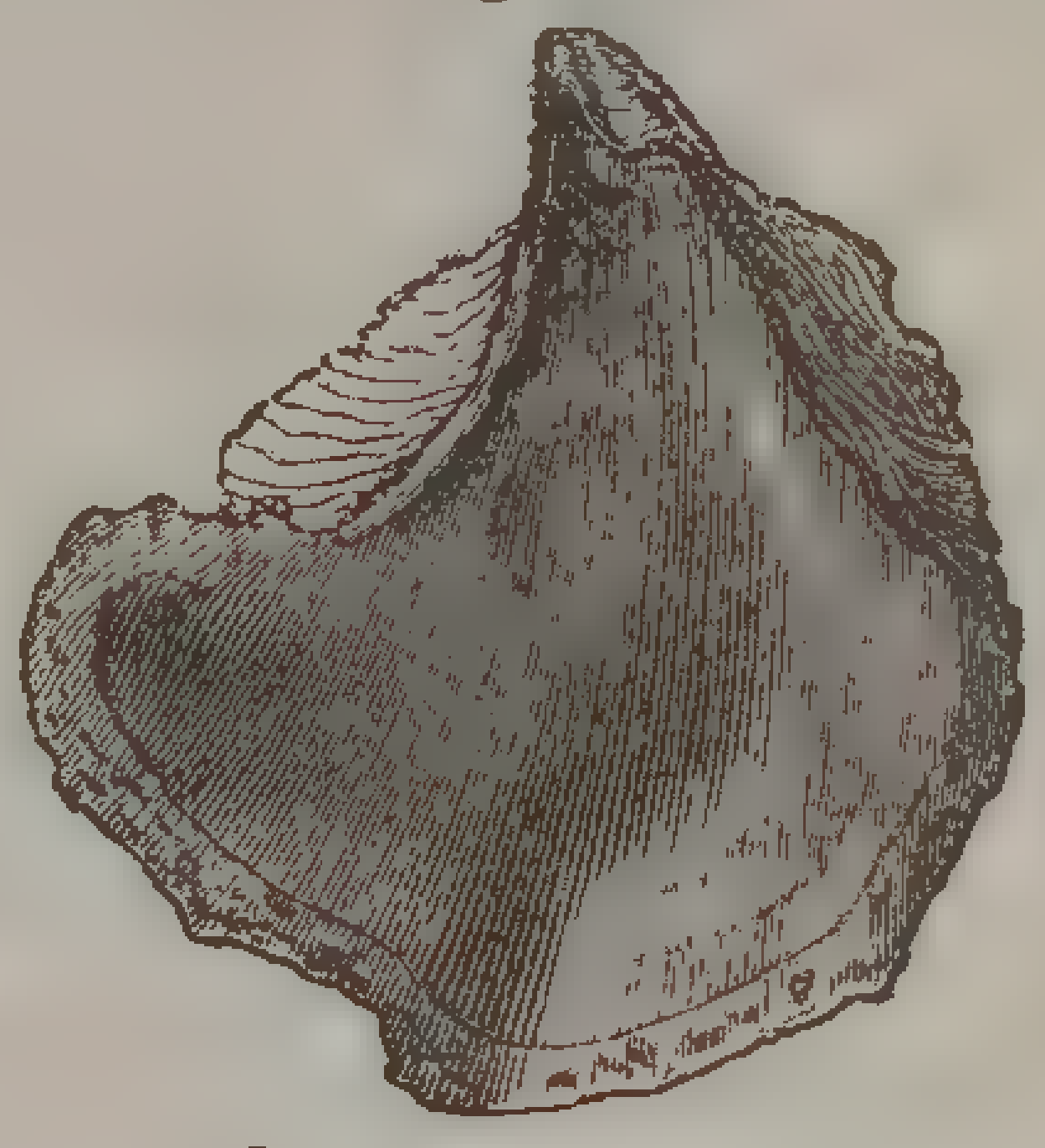
Among the characteristic fossils may be mentioned *Cardium striatulum* (fig. 349.) and *Ostrea deltoidea* (fig. 350.), the latter found in the Kimmeridge clay throughout England and the north of France, and also in Scotland, near Brora. The *Gryphæa virgula* (fig. 351.),

Fig. 349.



Cardium striatulum.
Kimmeridge clay, Hartwell.

Fig. 350.



Ostrea deltoidea.

Fig. 351.

Gryphæa virgula.
Upper Oolite: Kimmeridge clay. ¼ nat. size.

also met with in the same clay near Oxford, is so abundant in the Upper Oolite of parts of France as to have caused the deposit to be termed "marnes à gryphées virgules." Near Clermont, in Argonne, a few leagues from St. Menehould, where these indurated marls crop out from beneath the gault, I have seen them, on decomposing, leave the surface of every ploughed field literally strewed over with this fossil oyster. The *Trigonellites latus* (*Aptychus*, of some authors) (fig. 352.) is also widely dispersed through this clay. The real nature of the shell, of which there are many species in oolitic rocks, is still a matter of conjecture. Some are of opinion that the two plates formed the gizzard of a cephalopod; for the living Nautilus has a gizzard with horny folds, and the Bulla is well known to possess one formed of calcareous plates.

Fig. 352.

Trigonellites latus. Kimmeridge clay.

The celebrated lithographic stone of Solenhofen, in Bavaria, belongs to one of the upper divisions of the oolite, and affords a remarkable example of the variety of fossils which may be preserved under favourable circumstances, and what delicate impressions of the tender parts of certain animals and plants may be retained where the sediment is of extreme fineness. Although the number of testacea in this slate is small, and the plants few, and those all marine, Count Münster had determined no less than 237 species of fossils when I saw his collection in 1833; and among them no less than seven *species* of flying lizards, or pterodactyls (see fig. 353.), six saurians, three tortoises, sixty species of fish, forty-six of crustacea, and twenty-six of insects. These insects, among which is a libellula, or dragon-fly, must have been blown out to sea, probably from the same land to which the flying lizards, and other contemporaneous reptiles, resorted.

Fig. 353.

Skeleton of *Pterodactylus crassirostris.*
Oolite of Pappenheim, near Solenhofen.

MIDDLE OOLITE.

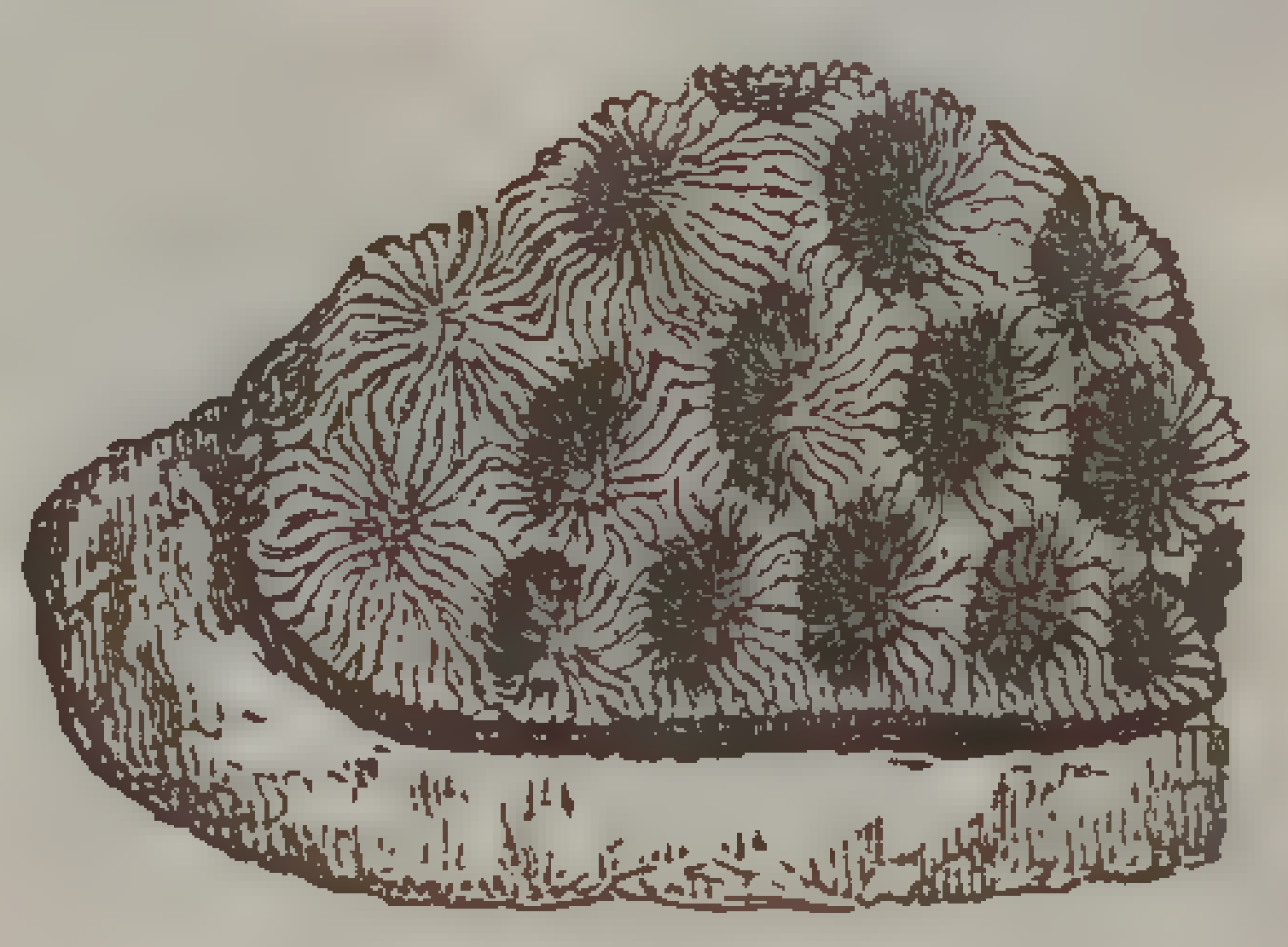
Coral Rag. — One of the limestones of the Middle Oolite has been called the "Coral Rag," because it consists, in part, of continuous beds of petrified corals, for the most part retaining the position in which they grew at the bottom of the sea. In their forms they more frequently resemble the reef-building poliparia of the Pacific than do the corals of any other member of the Oolite. They belong chiefly to the genera *Thecosmilia* (fig. 354.), *Protoseris*, and *Thamnastræa*, and sometimes form masses of coral 15 feet thick. In the annexed figure of a *Thamnastræa* (fig. 355.), from this formation, it will be seen that the cup-shaped cavities are deepest on the right-hand side, and that they grow more and more shallow, until those on the left side are nearly filled up. The last-mentioned stars are supposed to represent a perfected condition, and the others an immature state. These coralline strata extend through the calcareous hills of the

Corals of the Coral Rag.

Fig. 354.

Thecosmilia annularis, Milne Edw. and J. Haime, Coral Rag, Steeple Ashton.

Fig. 355.



Thamnastræa. Coral Rag, Steeple Ashton.

N. W. of Berkshire, and north of Wilts, and again recur in Yorkshire, near Scarborough. The *Ostrea gregarea* (fig. 356.) is very characteristic of the formation in England and on the continent.

One of the limestones of the Jura, referred to the age of the English coral-rag, has been called "Nerinæan limestone" (Calcaire à Nérinées) by M. Thirria; *Nerinæa* being an extinct genus of univalve shells, much resembling the *Cerithium* in external form. The annexed section (fig. 357.) shows the curious form of the hollow part of each whorl, and also the perforation which passes up the middle of the columella. *N. Goodhallii* (fig. 358.) is another English species of the same genus, from a formation which seems to form a passage from the Kimmeridge clay to the coral rag.*

Fig. 356.

Ostrea gregarea. Coral rag, Steeple Ashton.

Fig. 357.

Nerinæa hieroglyphica. Coral rag.

Fig. 358.

Nerinæa Goodhallii, Fitton. Coral rag, Weymouth. ¼ nat. size.

A division of the oolite in the Alps, regarded by most geologists as coeval with the English coral rag, has been often named "Calcaire à Dicerates," or "Diceras limestone," from its containing abundantly a bivalve shell (see fig. 359.) of a genus allied to the *Chama*.

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* Fitton, Geol. Trans., Second Series, vol. iv. pl. 23. fig. 12.

Fig. 359.

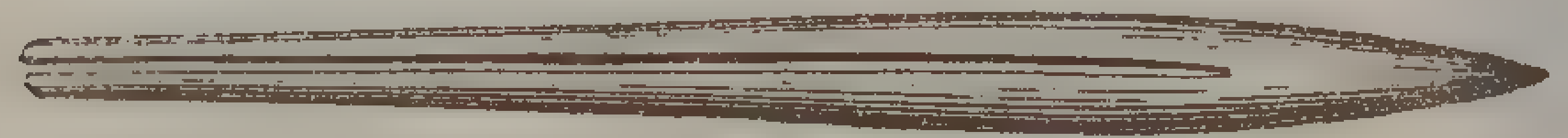
Cast of *Diceras arietina.*
Coral rag, France.

Fig. 360.

Cidaris coronata.
Coral rag.

Oxford Clay. — The coralline limestone, or "coral rag," above described, and the accompanying sandy beds, called "calcareous grits," of the Middle Oolite, rest on a thick bed of clay, called the "Oxford clay," sometimes not less than 500 feet thick. In this there are no corals, but great abundance of cephalopoda of the genera Ammonite and Belemnite. (See figs. 361, 362.) In some of the clay of very fine texture ammonites are very perfect, although somewhat compressed, and are seen to be furnished on each side of the aperture with a single horn-like projection (see fig. 362.). These were discovered in the cuttings of the Great Western Railway, near Chippenham, in 1841, and have been described by Mr. Pratt (*An. Nat. Hist.* Nov. 1841).

Fig. 361.



Belemnites hastatus. Oxford clay.

Fig. 362.

Ammonites Jason, Reinecke. Syn. *A. Elizabethæ*, Pratt.
Oxford clay, Christian Malford, Wiltshire.

Fig. 363.

Belemnites Puzosianus, D'Orb.
Oxford Clay, Christian Malford.
a, *a*. projecting processes of the shell or phragmocone.
b, *c*. broken exterior of a conical shell called the phragmocone, which is chambered within, or composed of a series of shallow concave cells pierced by a siphuncle.
c, *d*. The guard or osselet, which is commonly called the belemnite.

Similar elongated processes have been also observed to extend from the shells of some belemnites discovered by Dr. Mantell in the same clay (see fig. 363.), who, by the aid of this and other specimens, has been able to throw much light on the structure of this singular extinct form of cuttle-fish.*

LOWER OOLITE.

Cornbrash and Forest Marble. — The upper division of this series, which is more extensive than the preceding or Middle Oolite, is called in England the Cornbrash. It consists of clays and calcareous sandstones, which pass downwards into the Forest marble, an argillaceous limestone, abounding in marine fossils. In some places, as at Bradford, this limestone is replaced by a mass of clay. The sandstones of the Forest Marble of Wiltshire are often ripple-marked and filled with fragments of broken shells and pieces of drift-wood, having evidently been formed on a coast. Rippled slabs of fissile oolite are used for roofing, and have been traced over a broad band of country from Bradford, in Wilts, to Tetbury, in Gloucestershire. These calcareous tile-stones are separated from each other by thin seams of clay, which have been deposited upon them, and have taken their form, preserving the undulating ridges and furrows of the sand in such complete integrity, that the impressions of small footsteps, apparently of crabs, which walked over the soft wet sands, are still visible. In the same stone the claws of crabs, fragments of echini, and other signs of a neighbouring beach, are observed.†

Great Oolite. — Although the name of coral-rag has been appropriated, as we have seen, to a member of the Upper Oolite before described, some portions of the Lower Oolite are equally entitled in many places to be called coralline limestones. Thus the Great Oolite near Bath contains various

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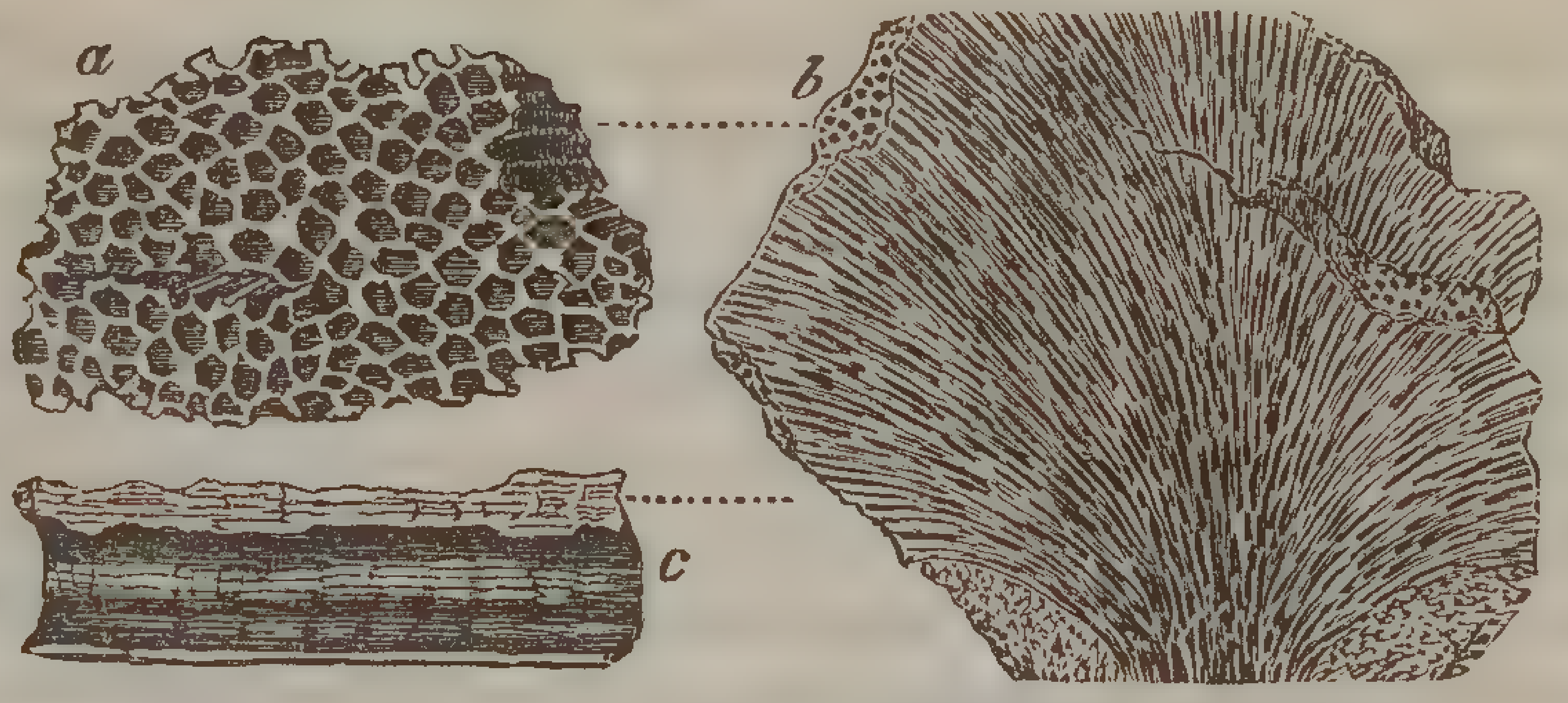
* See Phil. Trans. 1850, p. 393.

† P. Scrope, Geol. Proceed., March, 1831.

Fig. 364.



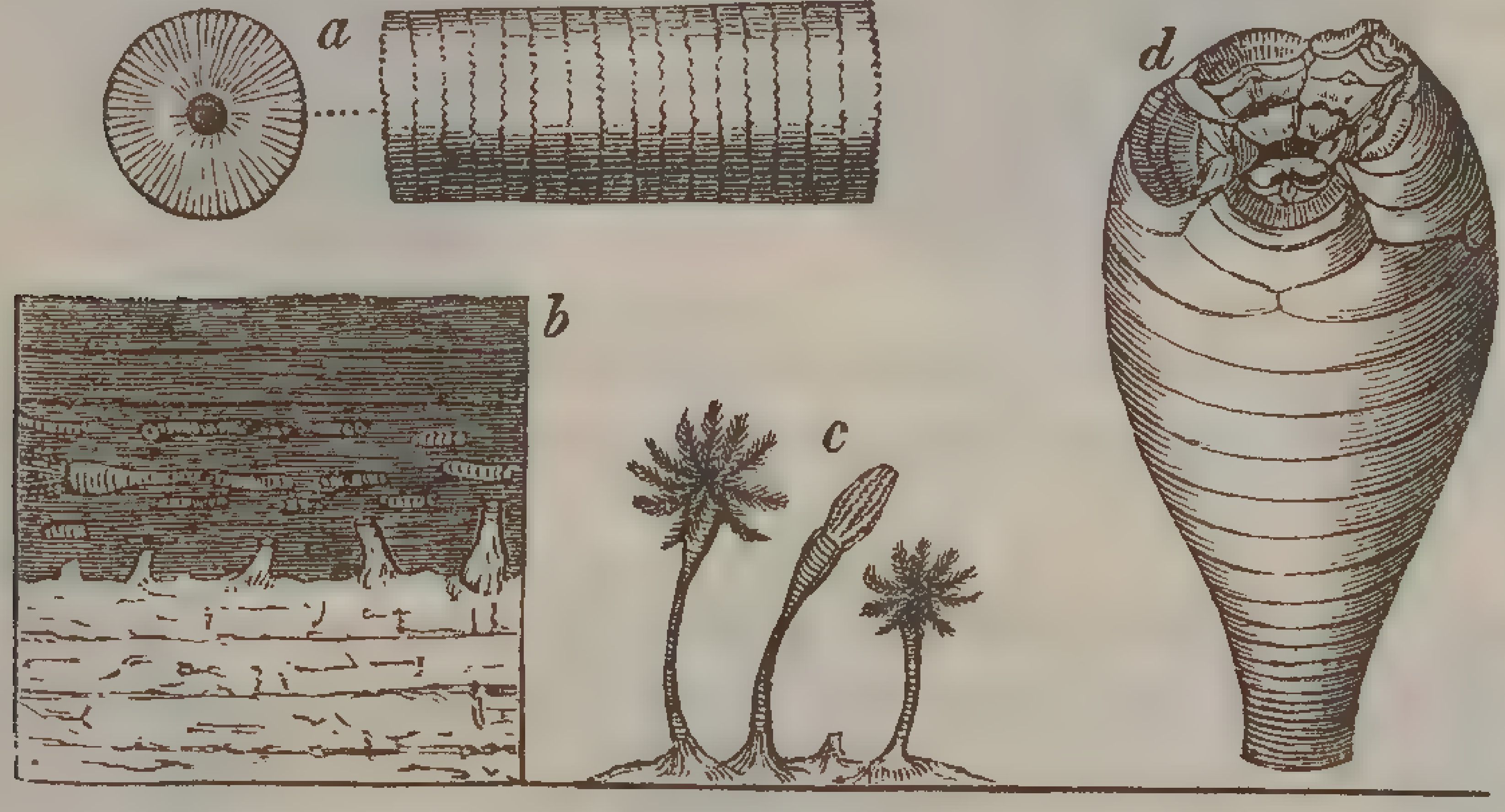
Eunomia radiata, Lamouroux. (*Calamophyllia*, Milne Edw.)

a. section transverse to the tubes.
b. vertical section, showing the radiation of the tubes.
c. portion of interior of tubes magnified, showing striated surface.

corals, among which the *Eunomia radiata* (fig. 364.) is very conspicuous, single individuals forming masses several feet in diameter; and having probably required, like the large existing brain-coral (*Meandrina*) of the tropics, many centuries before their growth was completed.

Different species of *Crinoideans*, or stone-lilies, are also common in the same rocks with corals; and, like them, must have enjoyed a firm bottom, where their root, or base of attachment, remained undisturbed for years (*c*, fig. 365.). Such fossils, therefore, are almost

Fig. 365.

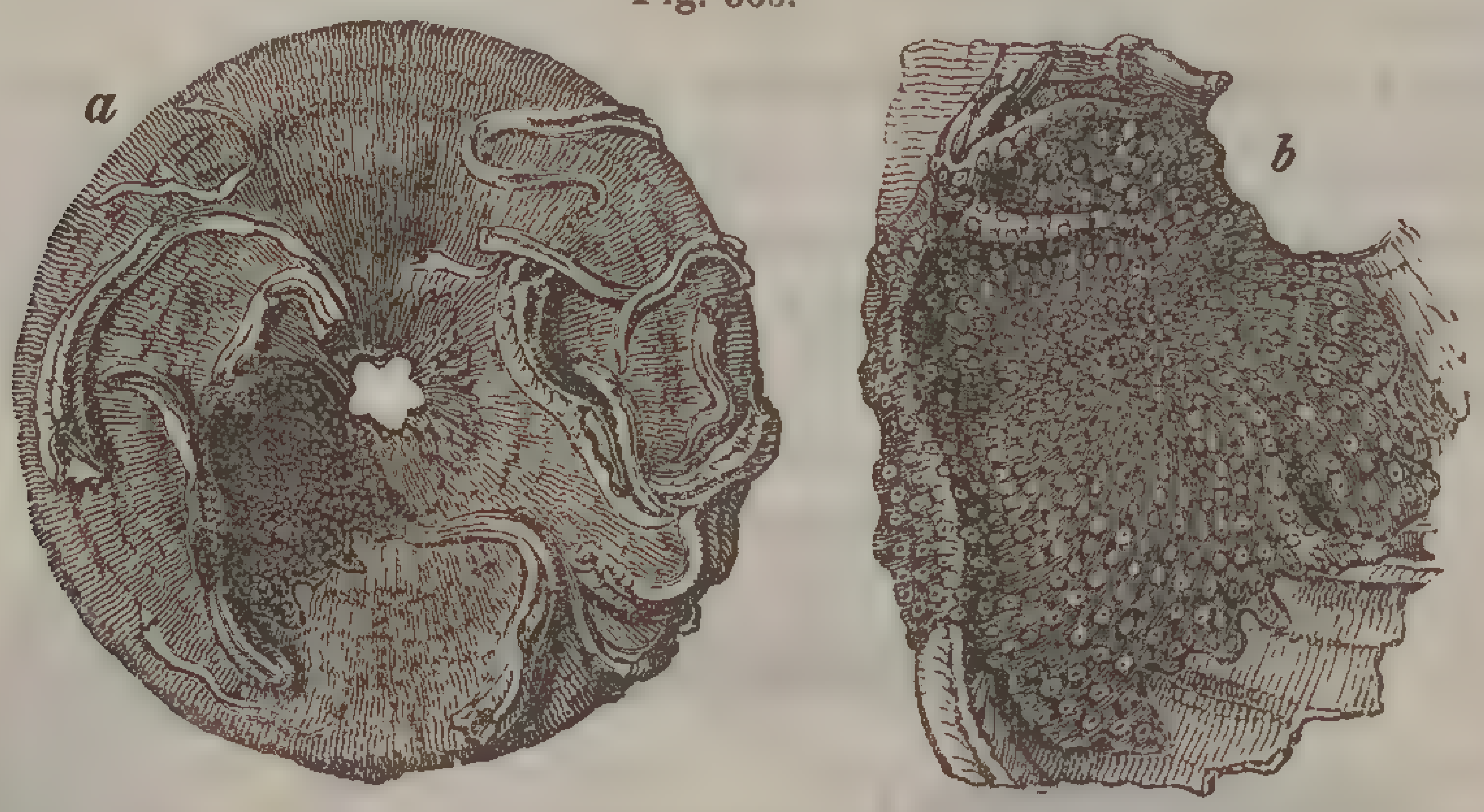


Apiocrinites rotundus, or Pear Encrinite; Miller. Fossil at Bradford, Wilts.

a. Stem of *Apiocrinites*, and one of the articulations, natural size.
b. Section at Bradford of great oolite and overlying clay, containing the fossil encrinites. See text.
c. Three perfect individuals of *Apiocrinites*, represented as they grew on the surface of the Great Oolite.
d. Body of the *Apiocrinites rotundus*.

confined to the limestones; but an exception occurs at Bradford, near Bath, where they are enveloped in clay. In this case, however, it appears that the solid upper surface of the "Great Oolite" had supported, for a time, a thick submarine forest of these beautiful zoophytes, until the clear and still water was invaded by a current charged with mud, which threw down the stone-lilies, and broke most of their stems short off near the point of attachment. The stumps still remain in their original position; but the numerous articulations, once composing the stem, arms, and body of the zoophyte, were scattered at random through the argillaceous deposit in which some now lie prostrate. These appearances are represented in the section *b*, fig. 365., where the darker strata represent the Bradford clay, which some geologists class with the Forest marble, others with the Great Oolite. The upper surface of the calcareous stone below is completely incrusted over with a continuous pavement, formed by the stony roots or attachments of the Crinoidea; and besides this evidence of the length of time they had lived on the spot, we find great numbers of single joints, or circular plates of the stem and body of the encrinite, covered over with *serpulæ*. Now these *serpulæ* could only have begun to grow after the death of some of the stone-lilies, parts of whose skeletons had been strewed over the floor of the ocean before the irruption of argillaceous mud. In some instances we find that, after the parasitic *serpulæ* were full grown, they had become incrusted over with a bryozoan, called *Berenicea diluviana;* and many generations of these molluscs had succeeded each other in the pure water before they became fossil.

Fig. 366.



a. Single plate or articulation of an Encrinite overgrown with *serpulæ* and *bryozoa*. Natural size. Bradford clay.
b. Portion of the same magnified, showing the bryozoan *Berenicea diluviana* covering one of the *serpulæ*.

We may, therefore, perceive distinctly that, as the pines and cycadeous plants of the ancient "dirt-bed," or fossil forest, of the Lower Purbeck were killed by submergence under fresh water, and soon buried beneath muddy sediment, so an invasion of argillaceous matter put a sudden stop to the growth of the Bradford Encrinites, and led to their preservation in marine strata.*

Such differences in the fossils as distinguish the calcareous and argillaceous deposits from each other, would be described by naturalists as arising out of a difference in the *stations* of species; but besides these, there are variations in the fossils of the higher, middle, and lower part of the oolitic series, which must be ascribed to that great law of change in organic life by which distinct assemblages of species have been adapted, at successive geological periods, to the varying conditions of the habitable surface. In a single district it is difficult to decide how far the limitation of species to certain minor

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* For a fuller account of these Encrinites, see Buckland's Bridgewater Treatise, vol. i. p. 429.

formations has been due to the local influence of *stations*, or how far it has been caused by time or the creative and destroying law above alluded to. But we recognize the reality of the last-mentioned influence, when we contrast the whole oolitic series of England with that of parts of the Jura, Alps, and other distant regions, where there is scarcely any lithological resemblance; and yet some of the same fossils remain peculiar in each country to the Upper, Middle, and Lower Oolite formations respectively. Mr. Thurmann has shown how remarkably this fact holds true in the Bernese Jura, although the argillaceous divisions, so conspicuous in England, are feebly represented there, and some entirely wanting.

The Bradford clay above alluded to is sometimes 60 feet thick, but, in many places, it is wanting; and, in others, where there are no limestones, it cannot easily be separated from the clays of the overlying "forest marble" and underlying "fuller's earth."

The calcareous portion of the Great Oolite consists of several shelly limestones, one of which, called the Bath Oolite, is much celebrated as a building-stone. In parts of Gloucestershire, especially near Minchinhampton, the Great Oolite, says Mr. Lycett, "must have been deposited in a shallow sea, where strong currents prevailed, for there are frequent changes in the mineral character of the deposit, and some beds exhibit false stratification. In others, heaps of broken shells are mingled with pebbles of rocks foreign to the neighbourhood, and with fragments of abraded madrepores, dicotyledonous wood, and crabs' claws. The shelly strata, also, have occasionally suffered denudation, and the removed portions have been replaced by clay."* In such shallow-water beds shells of the genera *Patella*,

Fig. 367

Terebratula digona.
Nat. size. Bradford clay.

Fig. 368

Purpuroidea nodulata. ¼ nat. size.
Great Oolite, Minchinhampton.

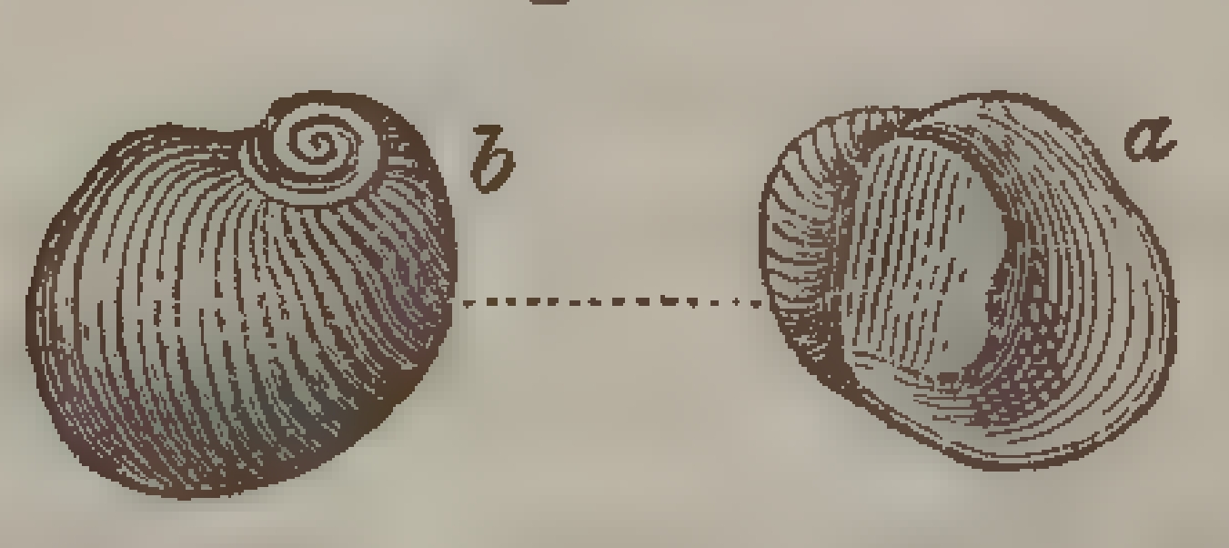
Fig. 369.

Cylindrites acutus, Sow.
Syn. *Actæon acutus.*
Great Oolite, Minchinhampton.

Fig. 370.

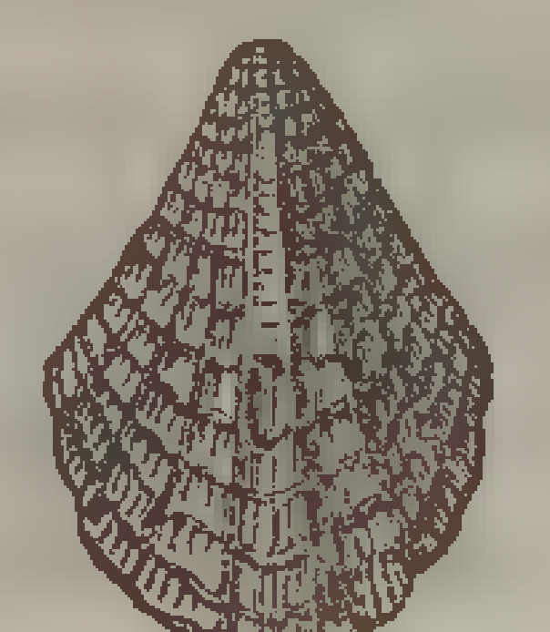
Patella rugosa, Sow.
Great Oolite.

Fig 371.



Nerita costulata, Desh.
Great Oolite.

Fig. 372.



Rimula (*Emarginula*) *clathrata*,
Sow. Great Oolite.

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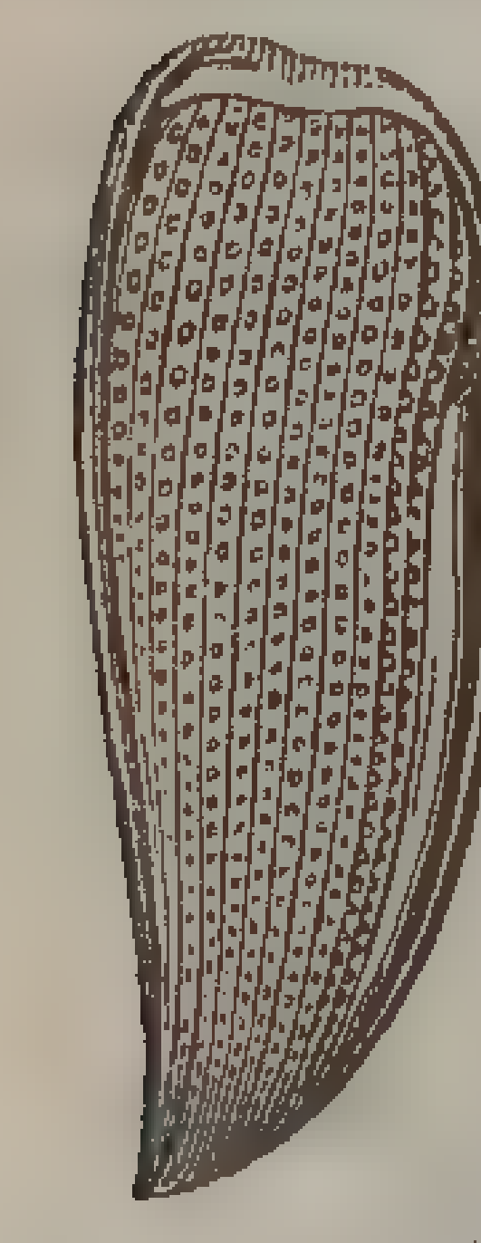
* Lycett, Geol. Journ. vol. iv. p. 183.

Nerita, *Rimula*, and *Cylindrites* are common (see figs. 369. to 372.); while cephalopods are rare, and, instead of ammonites and belemnites, numerous genera of carnivorous trachelipods appear. Out of one hundred and forty-two species of univalves obtained from the Minchinhampton beds, Mr. Lycett found no less than forty-one to be carnivorous. They belong principally to the genera *Buccinum*, *Pleurotoma*, *Rostellaria*, *Murex*, *Purpuroidea* (fig. 368.), and *Fusus*, and exhibit a proportion of zoophagous species not very different from that which obtains in warm seas of the recent period. These chronological results are curious and unexpected, since it was imagined that we might look in vain for the carnivorous trachelipods in rocks of such high antiquity as the Great Ooolite, and it was a received doctrine that they did not begin to appear in considerable numbers till the Eocene period, when those two great families of cephalopoda, the ammonites and belemnites, had become extinct.

Stonesfield slate.—The slate of Stonesfield has been shown by Mr. Lonsdale to lie at the base of the Great Oolite.* It is a slightly oolitic shelly limestone, forming large spheroidal masses imbedded in sand, only 6 feet thick, but very rich in organic remains. It contains some pebbles of a rock very similar to itself, and which may be portions of the deposit, broken up on a shore at low water or during storms, and redeposited. The remains of belemnites, trigoniæ, and other marine shells, with fragments of wood, are common, and impressions of ferns, cycadeæ, and other plants. Several insects, also, and, among the rest, the wing-covers of beetles, are perfectly preserved (see fig. 373.), some of them approaching nearly to the genus *Buprestis*.† The remains, also, of many genera of reptiles, such as *Pleiosaur*, *Crocodile*, and *Pterodactyl*, have been discovered in the same limestone.

Fig. 373.



Elytron of *Buprestis?* Stonesfield.

But the remarkable fossils for which the Stonesfield slate is most celebrated are those referred to the mammiferous class. The student should be reminded that in all the rocks described in the preceding chapters as older than the Eocene, no bones of any land quadruped, or of any cetacean, had been discovered until the *Spalacotherium* of the Purbeck beds came to light in 1854 (see above, p. 296.). Yet we have seen that terrestrial plants were not rare in the lower cretaceous formation, and that in the Wealden there was evidence of freshwater sediment on a large scale, containing various plants, and even ancient vegetable soils. We had also in the same Wealden many land-reptiles and winged insects, which render the absence of terrestrial quadrupeds the more striking. The want, however, of any bones of whales, seals, dolphins, and other aquatic mammalia, whether in the chalk or in the upper or middle oolite, is certainly still more remarkable. Formerly, indeed, a bone from the great oolite of Enstone, near Woodstock, in Oxfordshire, was cited, on the

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* Proceedings Geol. Soc. vol. i. p. 414.

† See Buckland's Bridgewater Treatise; and Brodie's Fossil Insects, where it is suggested that these elytra may belong to *Prionus*.

authority of Cuvier, as referable to this class. Dr. Buckland, who stated this in his Bridgewater Treatise*, had the kindness to send me the supposed ulna of a whale, that Prof. Owen might examine into its claims to be considered as cetacean. It is the opinion of that eminent comparative anatomist that it cannot have belonged to the cetacea, because the fore-arm in these marine mammalia is invariably much flatter, and devoid of all muscular depressions and ridges, one of which is so prominent in the middle of this bone, represented in the annexed cut (fig. 374.). In saurians, on the contrary, such ridges exist for the attachment of muscles; and to some animal of that class the bone is probably referable.

Fig. 374.

Bone of a Reptile, formerly supposed to be the ulna of a Cetacean; from the Great Oolite of Enstone, near Woodstock.

These observations are made to prepare the reader to appreciate more justly the interest felt by every geologist in the discovery in the Stonesfield slate of no less than seven specimens of lower jaws of mammiferous quadrupeds, belonging to three different species and to two distinct genera, for which the names of *Amphitherium* and *Phascolotherium* have been adopted. When Cuvier was first shown one of these fossils in 1818, he pronounced it to belong to a small ferine mammal, with a jaw much resembling that of an opossum, but differing from all known ferine genera, in the great number of the molar teeth, of which it had at least ten in a row. Since that period, a much more perfect specimen of the same fossil, obtained by Dr. Buckland (see fig. 375.), has been examined by Prof. Owen, who finds that the jaw contained on the whole twelve molar teeth, with the socket of a small canine, and three small incisors, which are *in situ*, altogether amounting to sixteen teeth on each side of the lower jaw.

The only question which could be raised respecting the nature of these fossils was, whether they belonged to a mammifer, a reptile, or a fish. Now on this head the osteologist observes that each of the seven half jaws is composed of but one single piece, and not of two or more separate bones, as in fishes and most reptiles, or of two bones, united by a suture, as in some few species belonging to those classes.

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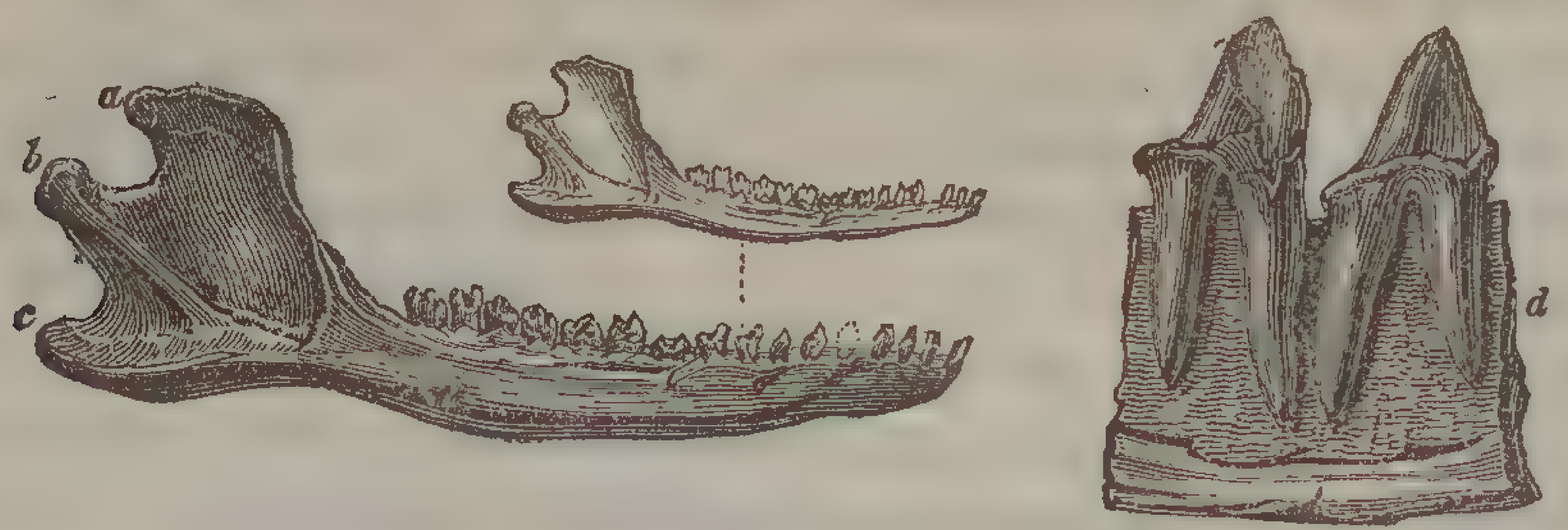
* Vol. i. p. 115.

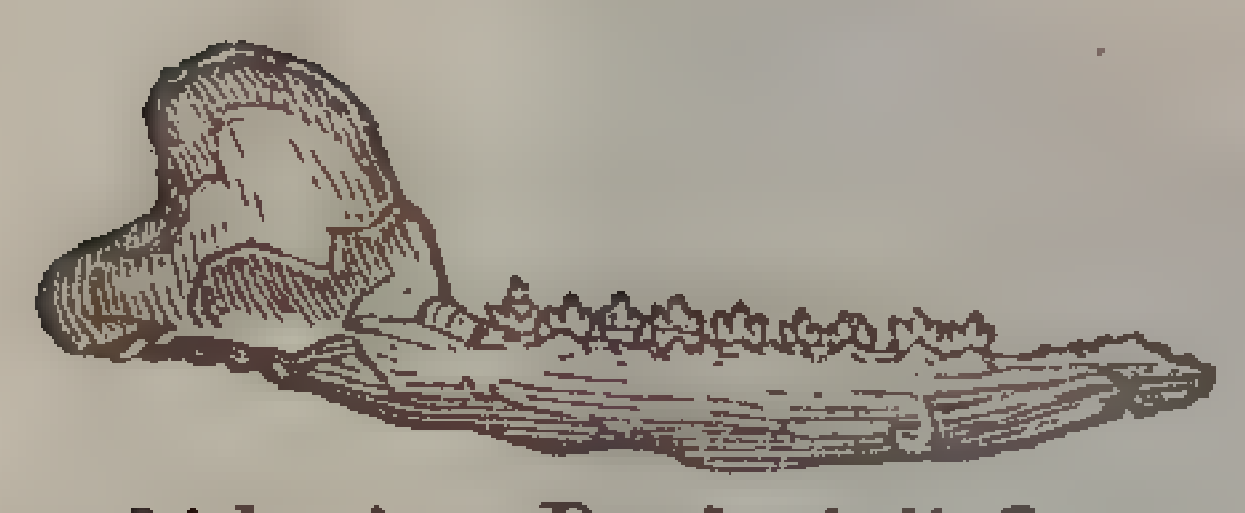
Fig. 375.

Natural size.



Amphitherium Prevostii, Cuv. Sp. Stonesfield Slate.
a. coronoid process. *b.* condyle. *c.* angle of jaw. *d.* double-fanged molars.

Fig. 376.



Amphitherium Broderipii, Owen. Natural size. Stonesfield Slate.

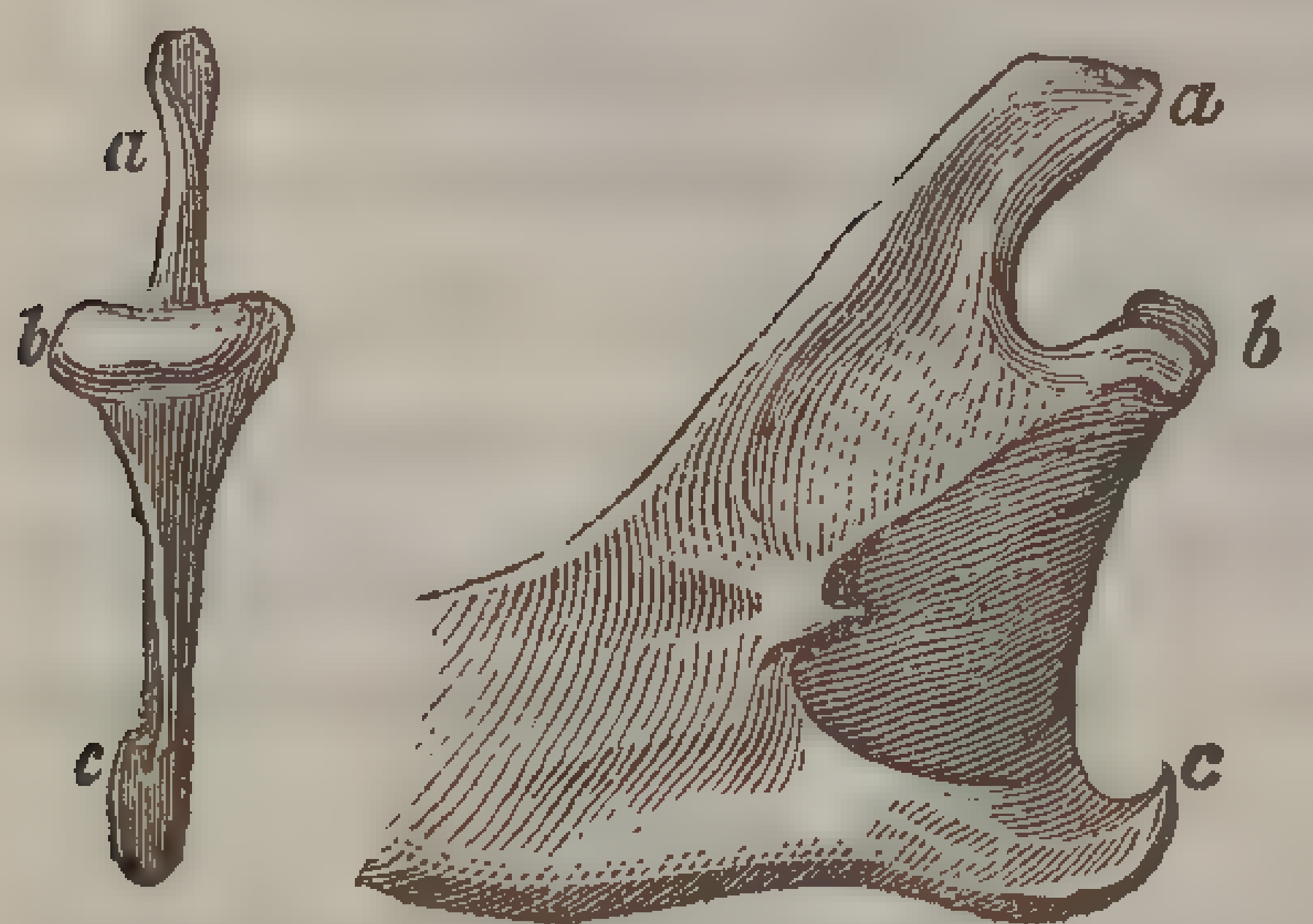
The condyle, moreover (*b*, fig. 375.), or articular surface, by which the lower jaw unites with the upper, is convex in the Stonesfield specimens, and not concave as in fishes and reptiles. The coronoid process (*a*, fig. 375.) is well developed, whereas it is wanting or very small, in the inferior classes of vertebrata. Lastly, the molar teeth in the *Amphitherium* and *Phascolotherium* have complicated crowns and two roots (see *d*, fig. 375.), instead of being simple and with single fangs.*

The only question, therefore, which could fairly admit of controversy was limited to this point, whether the fossil mammalia found in the lower oolite of Oxfordshire ought to be referred to the marsupial quadrupeds, or to the ordinary placental series. Cuvier had long ago pointed out a peculiarity in the form of the angular process (*c*, figs. 380. and 381.) of the lower jaw, as a character of the genus

Fig. 377.

Tupaia Tana.
Right ramus of lower jaw.
Natural size.
A recent insectivorous mammal from Sumatra.

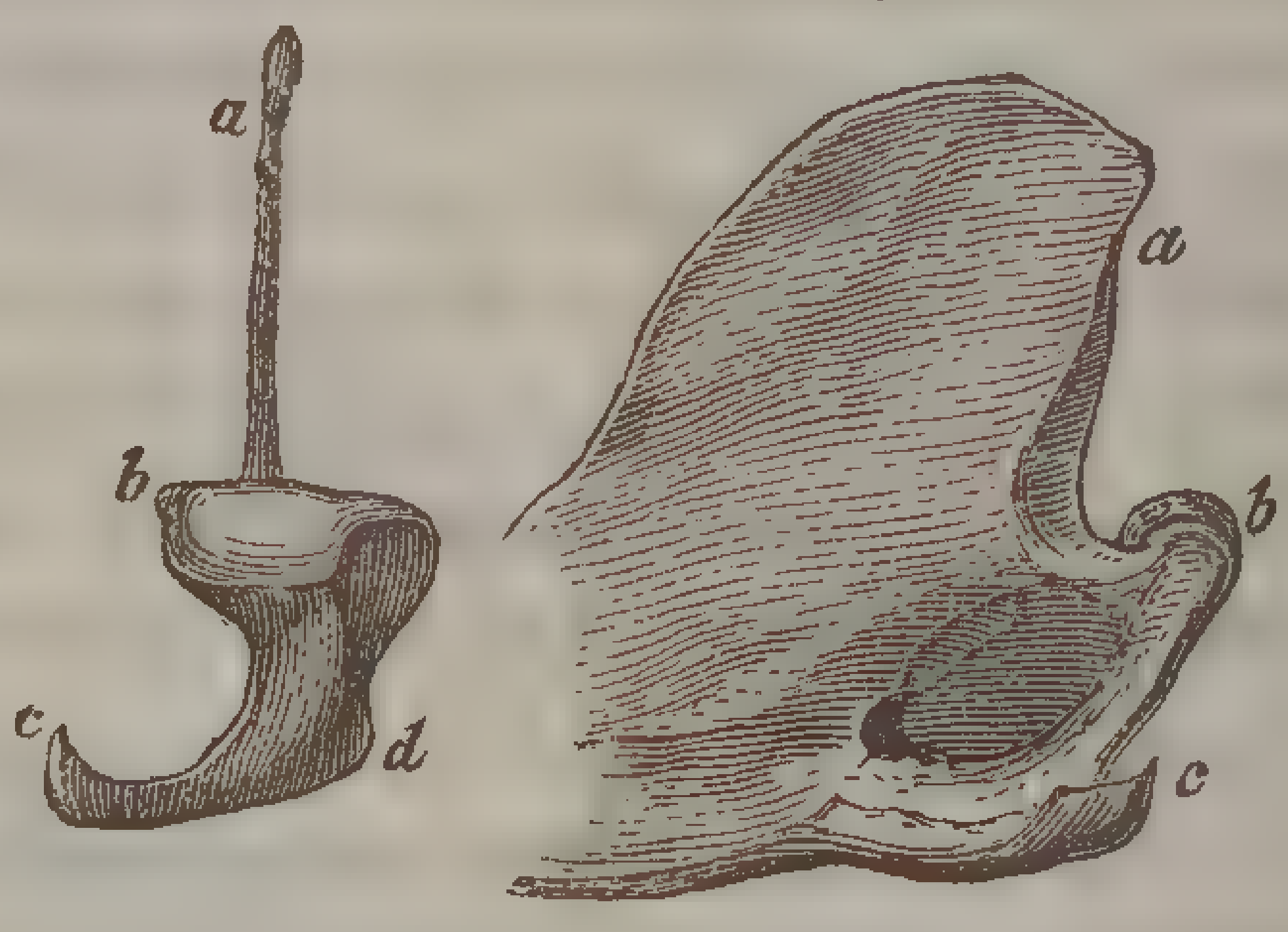
Fig. 378. Fig. 379.



Part of lower jaw of *Tupaia Tana;* twice natural size.

Fig. 378. End view seen from behind, showing the very slight inflection of the angle at *c*.
Fig. 379. Side view of same.

Fig. 380. Fig. 381.



Part of lower jaw of *Didelphys Azaræ;* recent, Brazil. Natural size.

Fig. 380. End view seen from behind, showing the inflection of the angle of the jaw, *c*, *d*.
Fig. 381. Side view of same.

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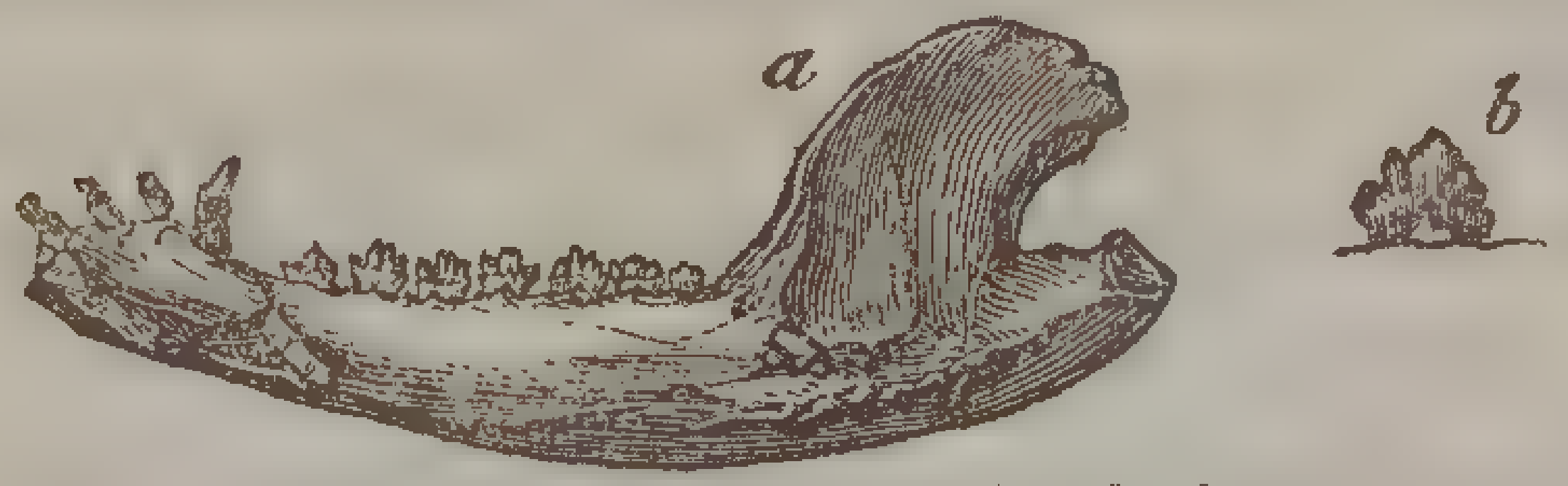
* I have given a figure in the Principles of Geology, chap. ix., of another Stonesfield specimen of *Amphitherium Prevostii*, in which the sockets and roots of the teeth are finely exposed.

Didelphys; and Prof. Owen has since established its generality in the entire marsupial series. In all these pouched quadrupeds, this process is turned inwards, as at *c d*, fig. 380. in the Brazilian opossum, whereas in the placental series, as at *c*, figs. 378. and 379., there is an almost entire absence of such inflection. The *Tupaia Tana* of Sumatra has been selected by my friend Mr. Waterhouse for this illustration, because that small insectivorous quadruped bears a great resemblance to those of the Stonesfield *Amphitherium*. By clearing away the matrix from the specimen of *Amphitherium Prevostii* above represented (fig. 375.) Prof. Owen ascertained that the angular process (*c*) bent inwards in a slighter degree than in any of the known marsupialia; in short, the inflection does not exceed that of the mole or hedgehog. This fact turns the scale in favour of its affinities to the placental insectivora. Nevertheless, the *Amphitherium* offers some points of approximation in its osteology to the marsupials, especially to the *Myrmecobius*, a small insectivorous quadruped of Australia, which has nine molars on each side of the lower jaw, besides a canine and three incisors.*

Another species of *Amphitherium* has been found at Stonesfield (fig. 376. p. 312.), which differs from the former (fig. 375.) principally in being larger.

The second mammiferous genus discovered in the same slates was named originally by Mr. Broderip *Didelphys Bucklandi* (see fig. 382.),

Fig. 382.



Phascolotherium Bucklandi, Broderip, sp.
a. natural size. *b*. molar of same magnified.

and has since been called *Phascolotherium* by Owen. It manifests a much stronger likeness to the marsupials in the general form of the jaw, and in the extent and position of its inflected angle, while the agreement with the living genus *Didelphys* in the number of the premolar and molar teeth is complete.†

On reviewing, therefore, the whole of the osteological evidence, it will be seen that we have every reason to presume that the *Amphitherium* and *Phascolotherium* of Stonesfield represent both the placental and marsupial classes of mammalia; and if so, they warn us in a most emphatic manner, not to found rash generalizations respecting the non-existence of certain classes of animals at particular periods of the past on mere negative evidence. The singular accident of our having as yet found nothing but the lower jaws of seven individuals, and no other bones of their skeletons, is alone sufficient to demonstrate the fragmentary manner in which the memorials of an

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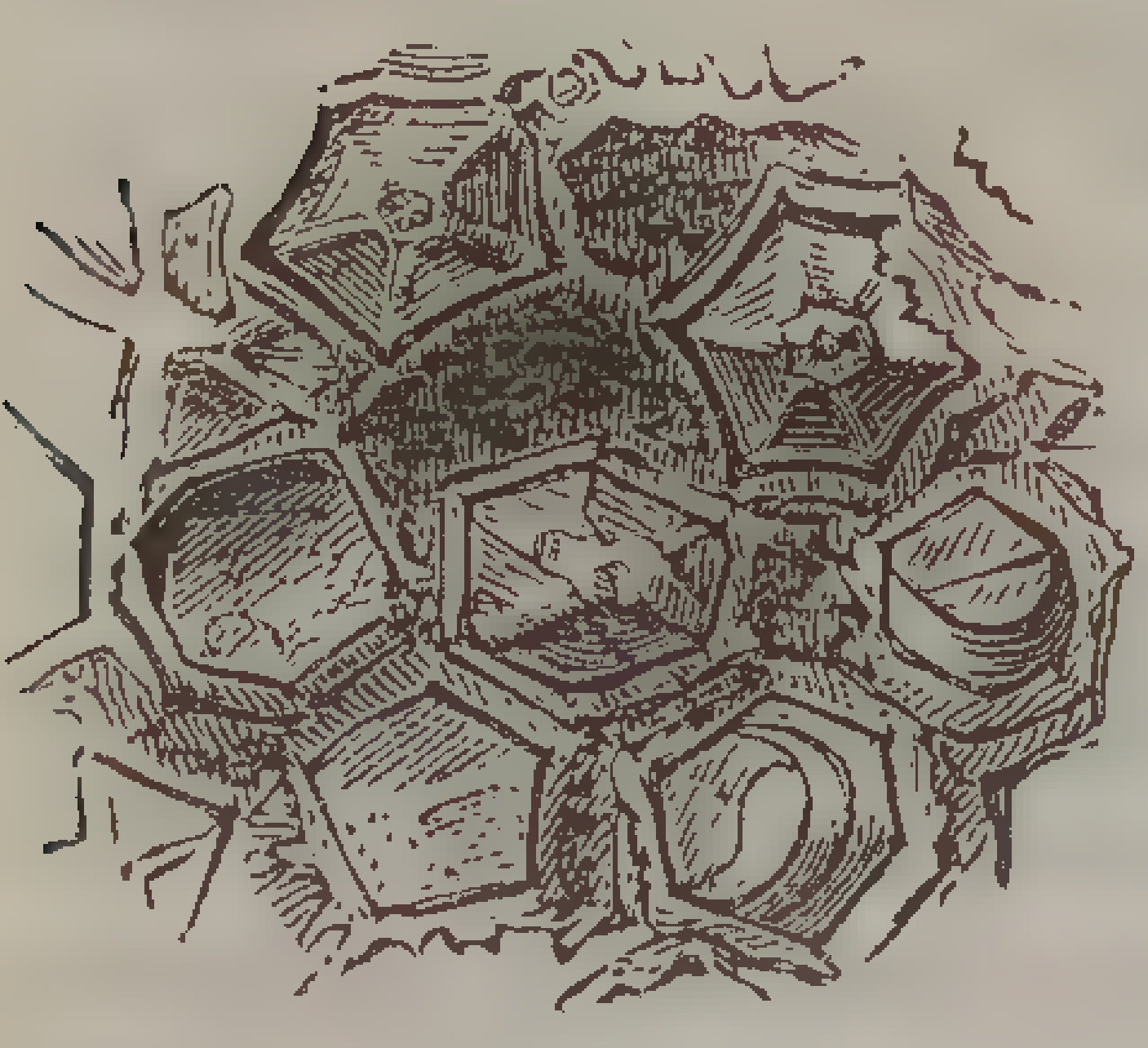
* A figure of this recent *Myrmecobius* will be found in the Principles, chap. ix.

† Owen's British Fossil Mammals, p. 62.

ancient terrestrial fauna are handed down to us. We can scarcely avoid suspecting that the two genera above described may have borne a like insignificant proportion to the entire assemblage of warm-blooded quadrupeds which flourished in the islands of the oolitic sea.

Prof. Owen has remarked that, as the marsupial genera, to which the *Phascolotherium* is most nearly allied, are now confined to New South Wales and Van Diemen's Land, so also is it in the Australian seas, that we find the *Cestracion*, a cartilaginous fish which has a bony palate, allied to those called *Acrodus* (see fig. 412. p. 322.) and *Strophodus*, so common in the oolite and lias. In the same Australian seas, also, near the shore, we find the living *Trigonia*, a genus of mollusca so frequently met with in the Stonesfield slate. So, also, the Araucarian pines are now abundant, together with ferns, in Australia and its islands, as they were in Europe in the oolitic period. Endogens of the most perfect structure are met with in oolitic rocks, as, for example, the *Podocarya* of Buckland, a fruit allied to the *Pandanus*, found in the Inferior Oolite (see fig. 383.).

Fig. 383.



Portion of a fossil fruit of *Podocarya* magnified. (Buckland's Bridgw. Treat. Pl. 63.) Inferior Oolite, Charmouth, Dorset.

The Stonesfield slate, in its range from Oxfordshire to the north-east, is represented by flaggy and fissile sandstones, as at Collyweston in Northamptonshire, where, according to the researches of Messrs. Ibbetson and Morris*, it contains many shells, such as *Trigonia angulata*, also found at Stonesfield. But the Northamptonshire strata of this age assume a more marine character, or appear at least to have been formed farther from land. They inclose, however, some fossil ferns, such as *Pecopteris polypodioides*, of species common to the oolites of the Yorkshire coast, where rocks of this age put on all the aspect of a true coal-field; thin seams of coal having actually been worked in them for more than a century.

In the north-west of Yorkshire, the formation alluded to consists of an upper and a lower carbonaceous shale, abounding in impressions of plants, divided by a limestone considered by many geologists as the representative of the Great Oolite; but the scarcity of marine fossils makes all comparisons with the subdivisions adopted in the south extremely difficult. A rich harvest of fossil ferns has been obtained from the upper carbonaceous shales and sandstones at Gristhorpe, near Scarborough (see figs. 384, 385.). The lower shales are well exposed in the sea-cliffs at Whitby, and are chiefly characterized by ferns and cycadeæ. They contain, also, a species of calamite, and a fossil called *Equisetum columnare*, which maintains an upright position in sandstone strata over a wide area. Shells of *Estheria*

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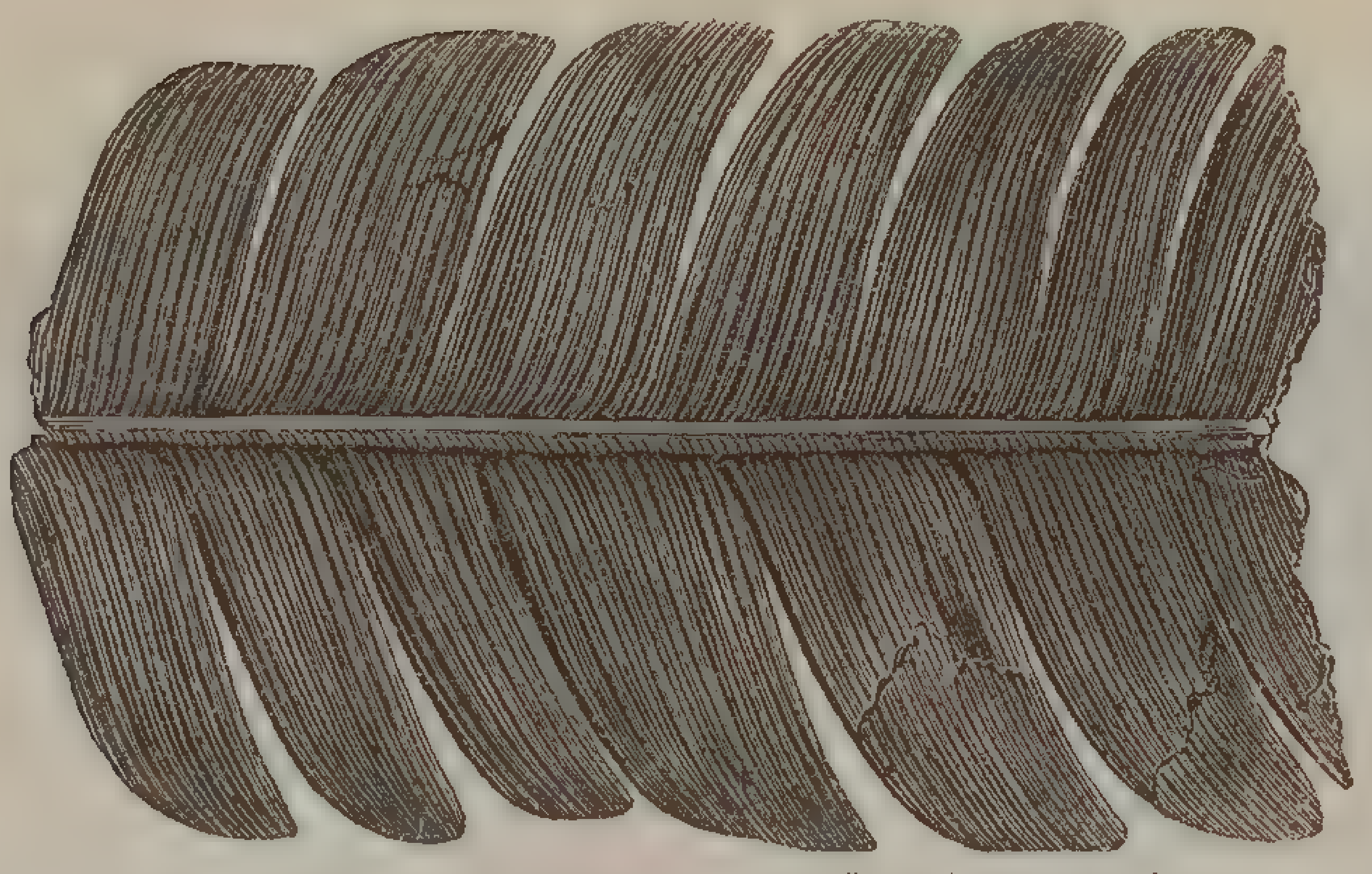
* Ibbetson and Morris, Report of Brit. Ass., 1847, p. 131.; and Morris, Geol. Journ., ix. p. 334.

Fig. 384.



Pterophyllum comptum. Syn. *Cycadites comptus.*
Upper sandstone and shale, Gristhorpe, near Scarborough.

Fig. 385.

Hemitelites Brownii, Goepp.
Syn. *Phlebopteris contigua*, Lind. & Hutt.
Upper carbonaceous strata, Lower Oolite, Gristhorpe, Yorkshire.

and *Unio*, collected by Mr. Bean from these Yorkshire coal-bearing beds, point to the estuary or fluviatile origin of the deposit.

At Brora, in Sutherlandshire, a coal formation, probably coeval with the above, or belonging to some of the lower divisions of the Oolitic period, has been mined extensively for a century or more. It affords the thickest stratum of pure vegetable matter hitherto detected in any secondary rock in England. One seam of coal of good quality has been worked 3½ feet thick, and there are several feet more of pyritous coal resting upon it.

Fig. 386.

Ostrea acuminata.
Fuller's Earth.

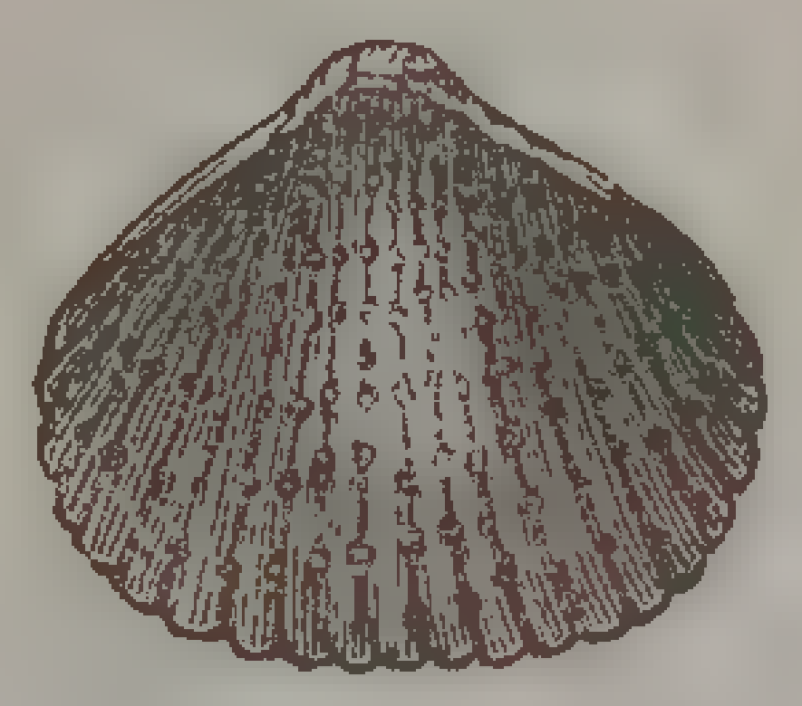
Fuller's Earth (*h.* Tab. p. 292.). — Between the Great and Inferior Oolite, near Bath, an argillaceous deposit, called "the fuller's earth," occurs; but it is wanting in the north of England. It abounds in the small oyster represented in fig. 386.

Inferior Oolite. — This formation consists of a calcareous freestone, usually of small thickness, which sometimes rests upon, or is replaced by, yellow sands, called the sands of the Inferior Oolite. These last, in their turn, repose upon the lias in the south and west of England. Among the characteristic shells of the Inferior Oolite, I may instance *Terebratula fimbria* (fig. 387.), *Rhynchonella spinosa* (fig. 388.), and *Pholadomya fidicula* (fig. 389.). The extinct genus *Pleurotomaria* is also a form very common in this division as well as in the Oolitic system

Fig. 387.

Terebratula fimbria.
Inferior Oolite.

Fig. 388.

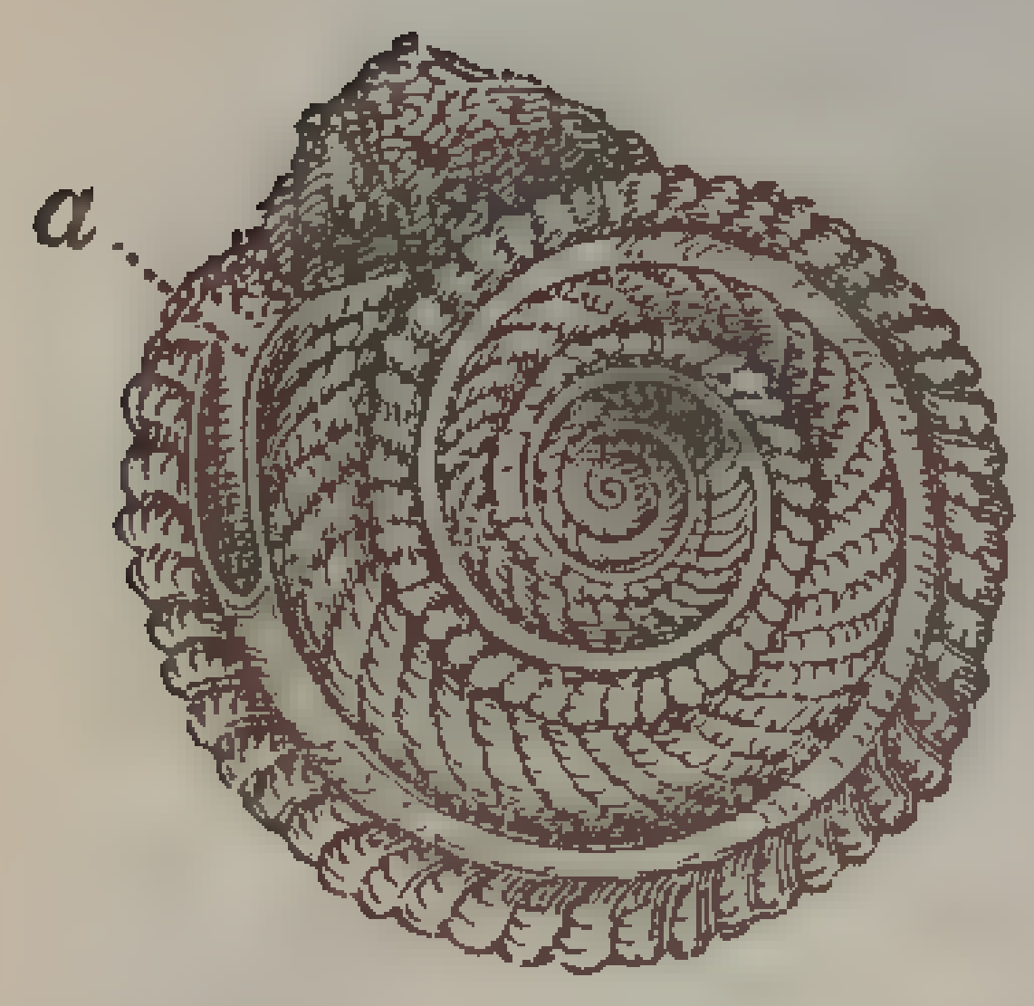


Rhynchonella spinosa.
Inferior Oolite.

Fig. 389.

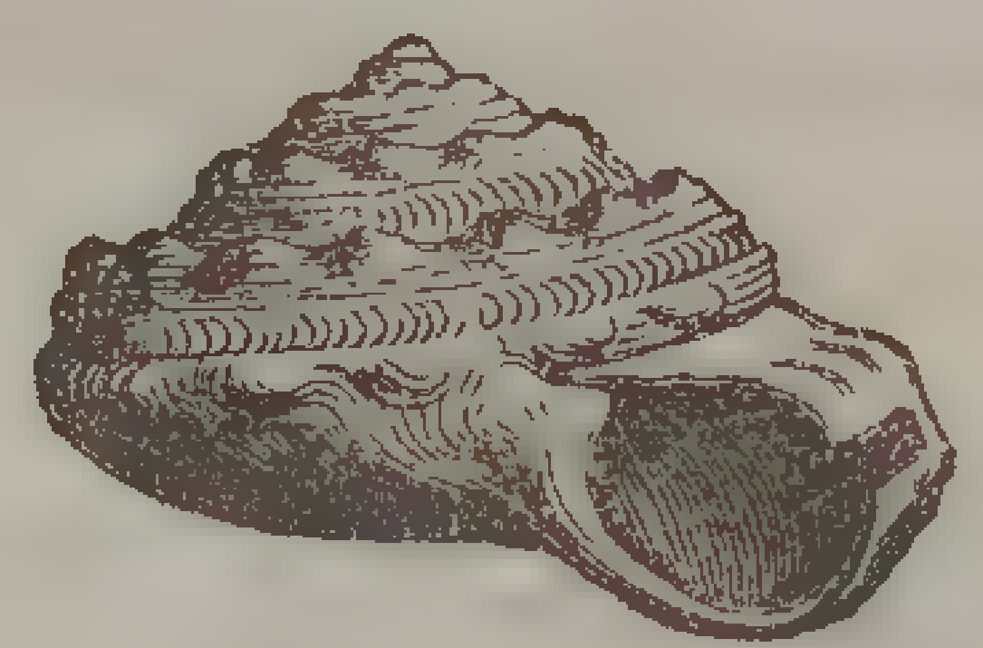
a. *Pholadomya fidicula.* $\frac{1}{3}$ nat. size. Inf. Ool
b. Heart-shaped anterior termination of the same.

Fig. 390.



Pleurotomaria granulata.
Ferruginous Oolite, Normandy.
Inferior Oolite, England.

Fig. 391.



Pleurotomaria ornata, Sow. Sp.
Inferior Oolite.

Fig. 392.

Dysaster ringens.
Inf. Ool. Somersetshire.

generally. It resembles the *Trochus* in form, but is marked by a deep cleft (*a*, fig. 390. and fig. 391.) on the right side of the mouth. The *Dysaster ringens* (fig. 392.) is an Echinoderm common to the inferior Oolite of England and France, as are the three Ammonites of which representations are here given (figs. 393, 394, 395.).

Fig. 393.

Ammonites Humphresianus.
Inferior Oolite.

As illustrations of shells having a great vertical range, I may allude to *Trigonia clavellata*, found in the Upper and Inferior Oolite, and *T. costata*, common to the Upper, Middle, and Lower Oolite; also *Ostrea Marshii* (fig. 396.), common to the Cornbrash of Wilts and the Inferior Oolite of Yorkshire; and *Ammonites striatulus* (fig. 397.) common to the Inferior Oolite and Lias.

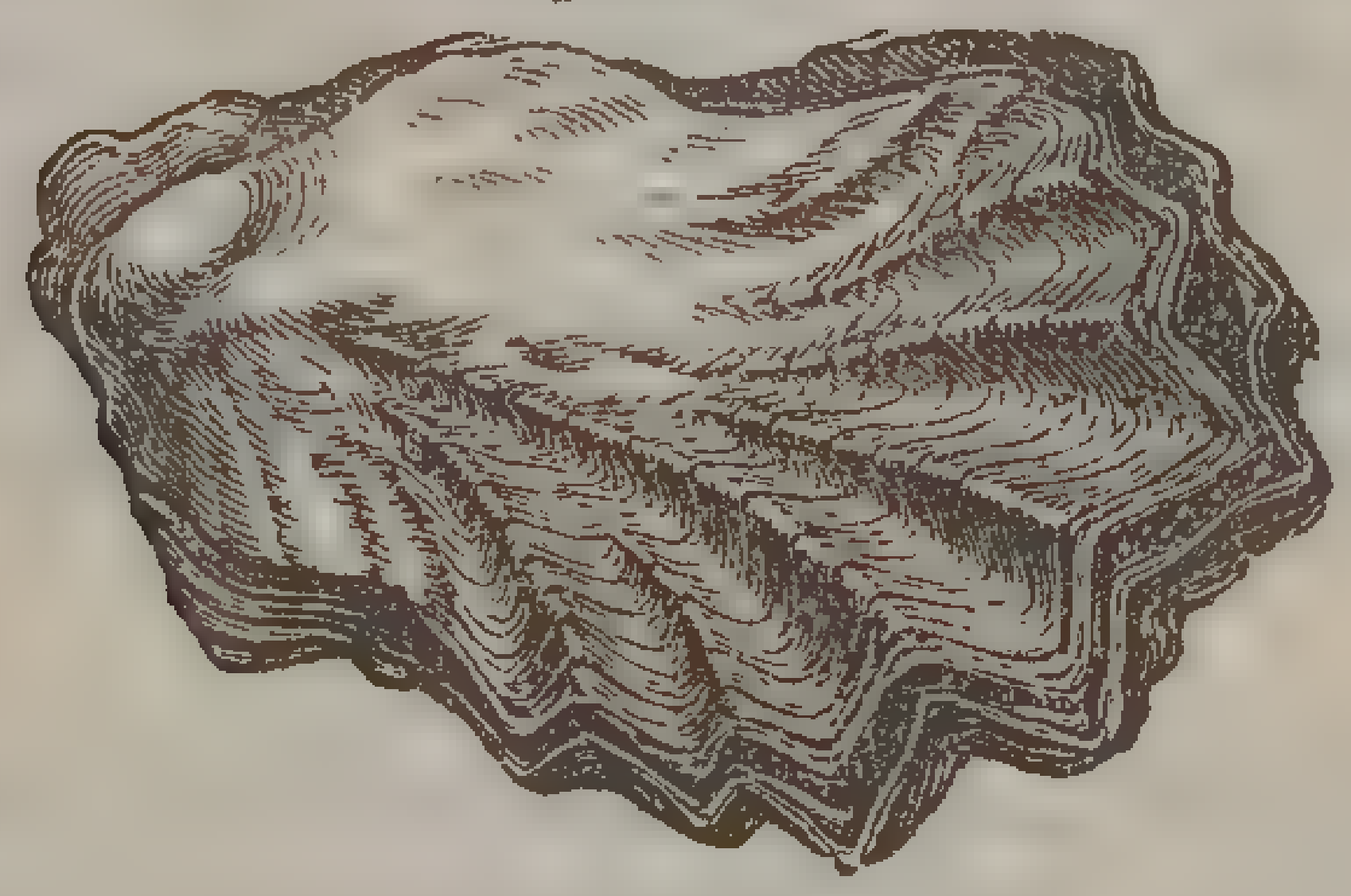
Fig. 394.

Ammonites margaritatus, D'Orb. Syn. *A. Stokesii*, Sow.
Lias.

Fig. 395.

Ammonites Braikenridgii, Sow.
Great Oolite, Scarborough.
Inf. Ool. Dundry; Calvados; &c.

Fig. 396.



Ostrea Marshii. ½ nat. size.
Middle and Lower Oolite.

Fig. 397.

Ammonites striatulus, Sow.
½ nat. size.
Inferior Oolite and Lias.

Such facts by no means invalidate the general rule, that certain fossils are good chronological tests of geological periods; but they serve to caution us against attaching too much importance to single species, some of which may have a wider, others a more confined vertical range. We have before seen that, in the successive tertiary formations there are species common to older and newer groups, yet these groups are distinguishable from one another by a comparison of the whole assemblage of fossil shells proper to each.

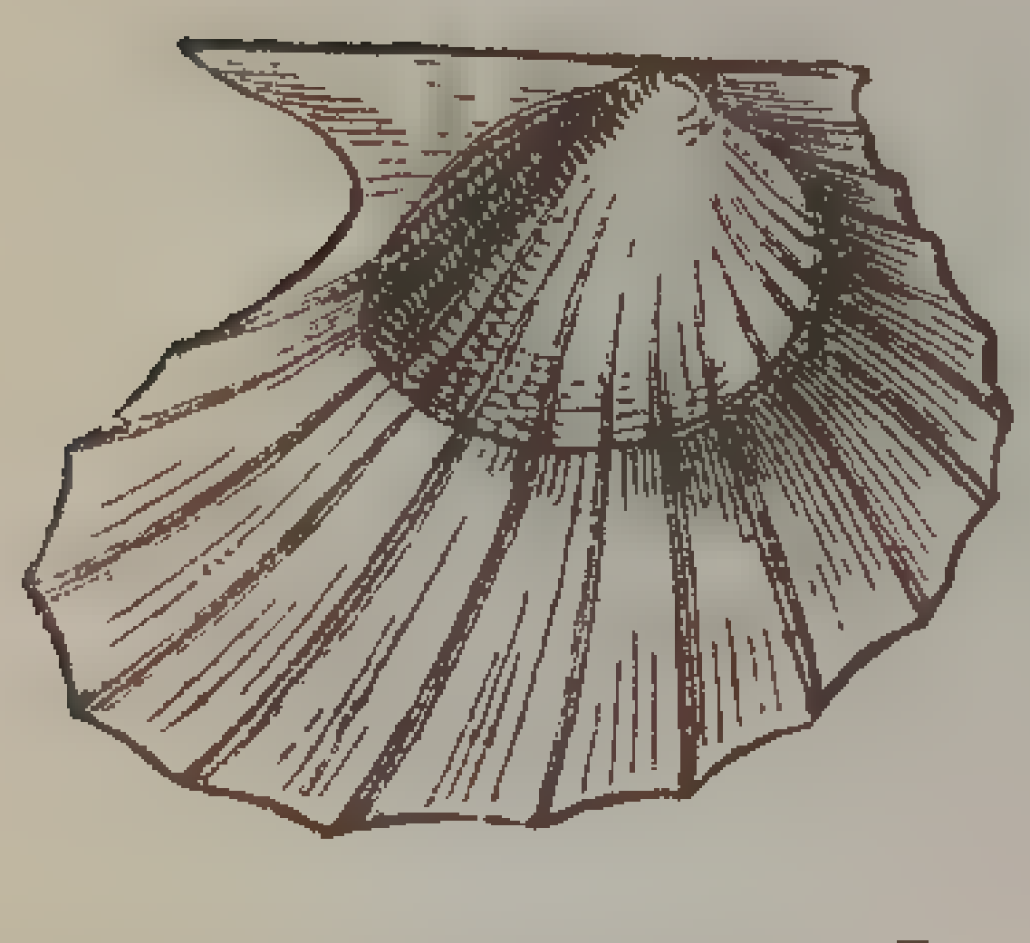
CHAPTER XXI.

JURASSIC GROUP — *continued.* LIAS.

Mineral character of Lias — Name of Gryphite limestone — Fossil shells and fish — Radiata — Ichthyodorulites — Reptiles of the Lias — Ichthyosaur and Plesiosaur — Marine Reptile of the Galapagos Islands — Sudden destruction and burial of fossil animals in Lias — Fluvio-marine beds in Gloucestershire, and insect limestone — Fossil plants — Origin of the Oolite and Lias, and of alternating calcareous and argillaceous formations — Oolitic coal-field of Virginia, in the United States.

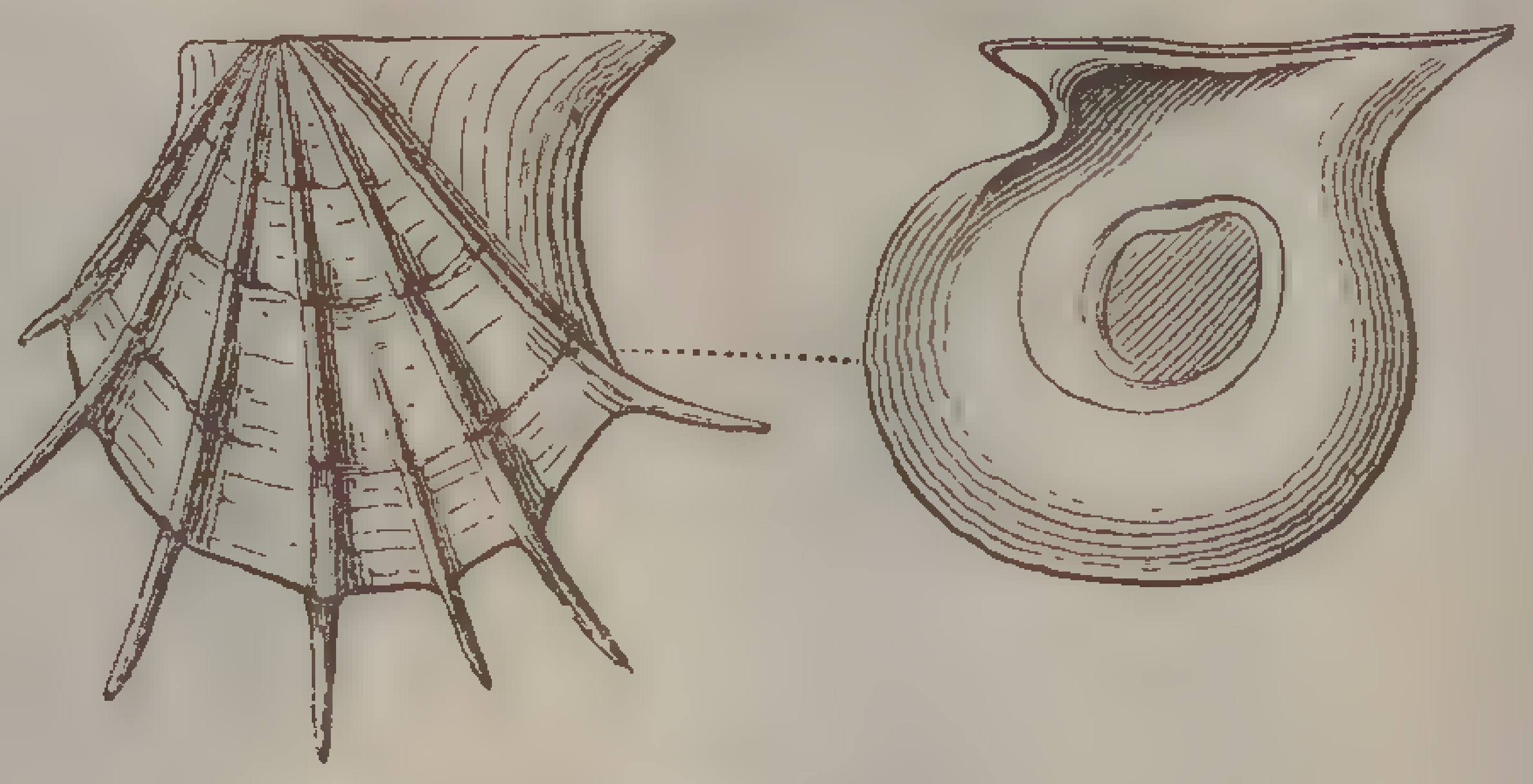
Lias. — The English provincial name of Lias has been very generally adopted for a formation of argillaceous limestone, marl, and clay, which forms the base of the Oolite, and is classed by many geologists as part of that group. They pass, indeed, into each other in some places, as near Bath, a sandy marl called the marlstone of the Lias being interposed, and partaking of the mineral characters of the lias and the inferior oolite. These last-mentioned divisions have also some fossils in common, such as the *Avicula inæquivalvis* (fig. 398.). Nevertheless the Lias may be traced throughout a great part of Europe as a separate and independent group, of considerable thickness, varying from 500 to 1000 feet, containing many peculiar fossils, and having a very uniform lithological aspect. Although usually conformable to the oolite, it is sometimes, as in the Jura, unconformable. In the environs of Lons-le-Saulnier, for instance, in the department of Jura, the strata of lias are inclined at an angle of about 45°, while the incumbent oolitic marls are horizontal.

Fig. 398.



Avicula inæquivalvis, Sow.
Lower Oolite.

Fig. 399.



Avicula cygnipes, Phil.
Marlstone, Gloucestershire; Lias, Yorkshire.

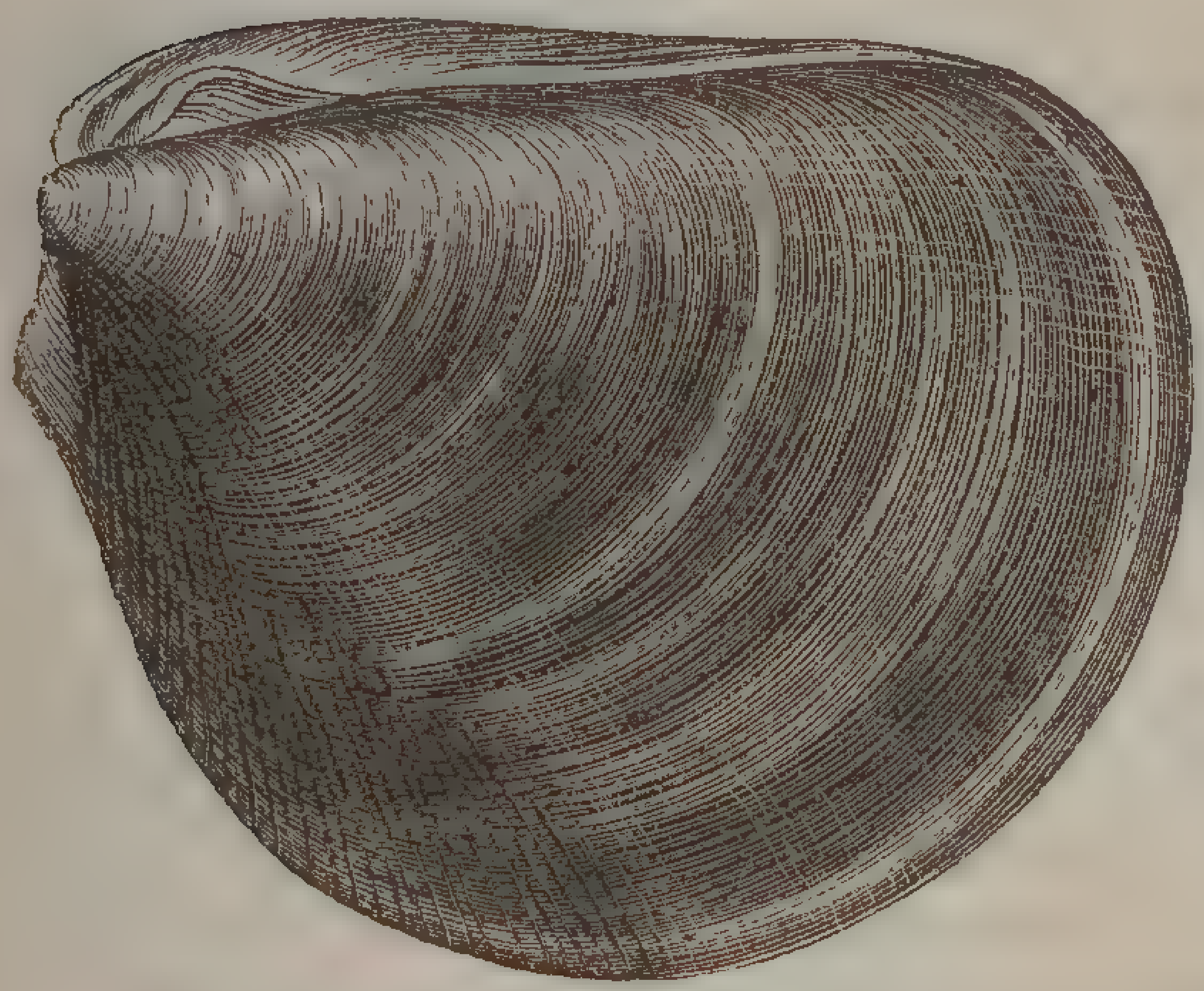
The peculiar aspect which is most characteristic of the Lias in England, France, and Germany is an alternation of thin beds of blue or grey limestone having a surface which becomes light-brown when weathered, these beds being separated by dark-coloured narrow argillaceous partings, so that the quarries of this rock, at a distance, assume a striped and riband-like appearance.*

The Lias comprises, 1. the Upper Lias—thin limestone beds with clay and shale; 2. the Marlstone—a coarse shelly limestone; and 3. the Lower Lias—consisting of limestone, shells, and clay. These divisions have certain fossils in common, and in some places pass the one into the other.

Although the prevailing colour of the limestone of this formation is blue, yet some beds of the lower lias are of a yellowish white colour, and have been called white lias. In some parts of France, near the Vosges mountains, and in Luxembourg, M. E. de Beaumont has shown that the lias containing *Gryphæa arcuata*, *Plagiostoma giganteum* (see fig. 400.), and other characteristic fossils becomes arenaceous; and around the Hartz, in Westphalia and Bavaria, the inferior parts of the lias are sandy, and sometimes afford a building-stone.

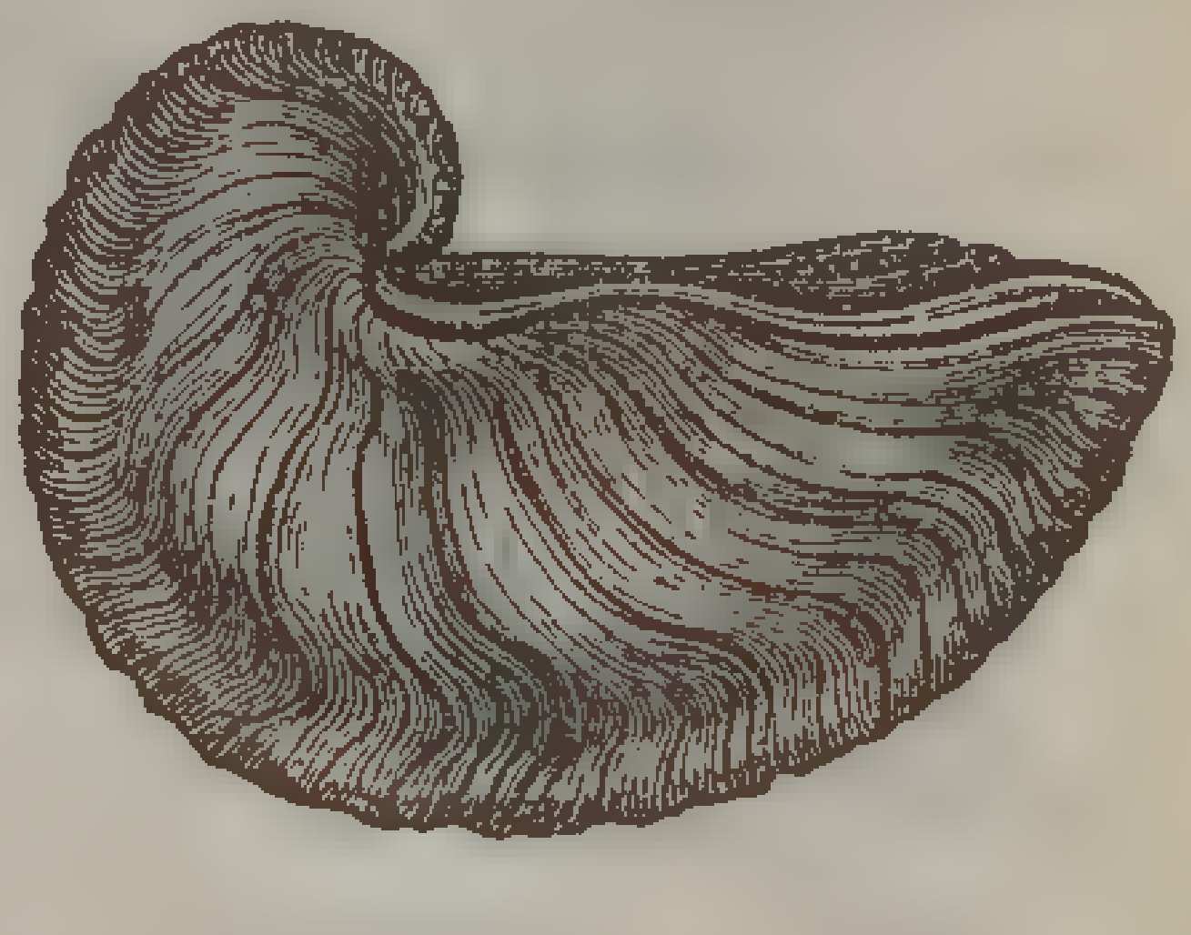
The name of Gryphite limestone has sometimes been applied to the lias, in consequence of the great number of shells which it contains of a species of oyster, or *Gryphæa* (fig. 401., see also fig. 30. p. 29.). A large heavy shell called *Hippopodium* (fig. 402.), allied to *Isocardia*, is also characteristic of the lower lias shales. The Lias formation is also remarkable for being the oldest of the secondary rocks in which brachiopoda of the genera *Spirifer* and *Leptæna* (figs. 403, 404.) occur: no less than nine species of *Spirifers* are enumerated by Mr. Davidson as belonging to the lias. These palliobranchiate mollusca predominate greatly in strata older than the trias; but, so far as we yet know, they did not survive the liassic epoch. The marine beds of the lias also abound in cephalopoda of the genera *Belemnites*, *Nautilus*, and *Ammonites* (see figs. 405, 406, 407.).

Fig. 400.



Plagiostoma (Lima) giganteum, Sow.
Inf. Ool. and Lias.

Fig. 401.



Gryphæa incurva, Sow.
(*G. arcuata*, Lam.)
Lias.

Among the Crinoids or Stone-lilies of the Lias, *Pentacrinus*

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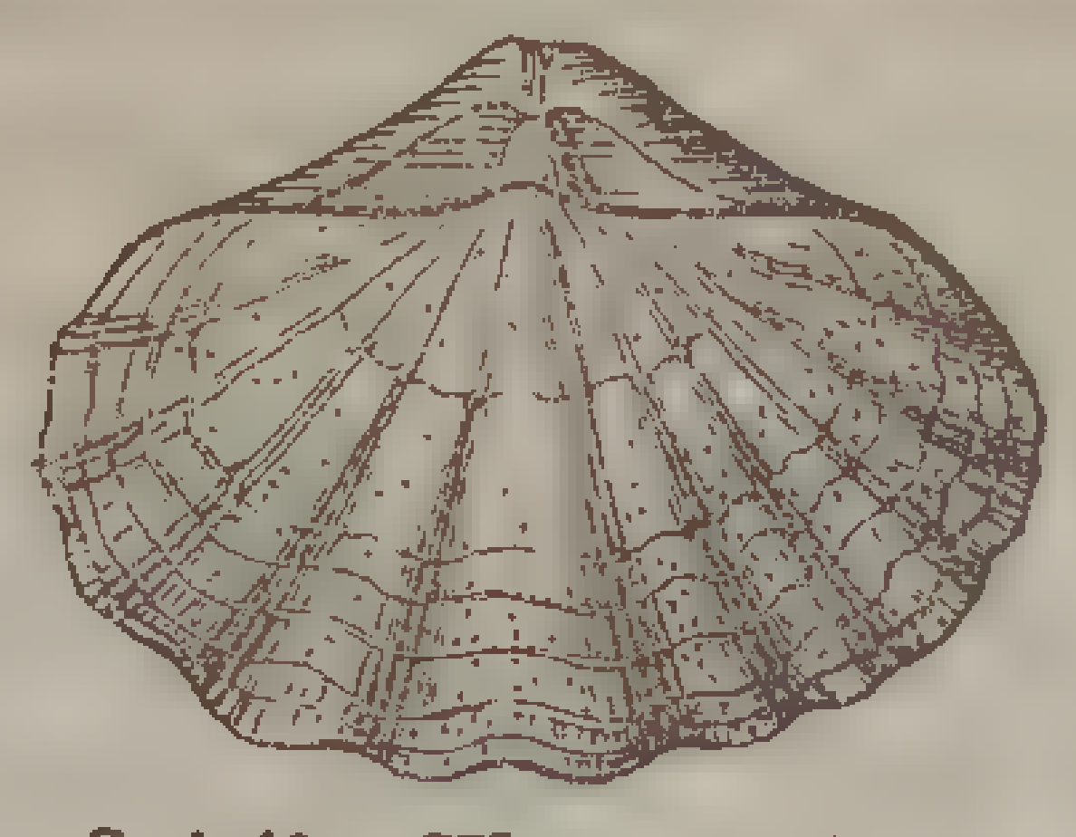
* Conyb. and Phil., p. 261.

Fig. 402.

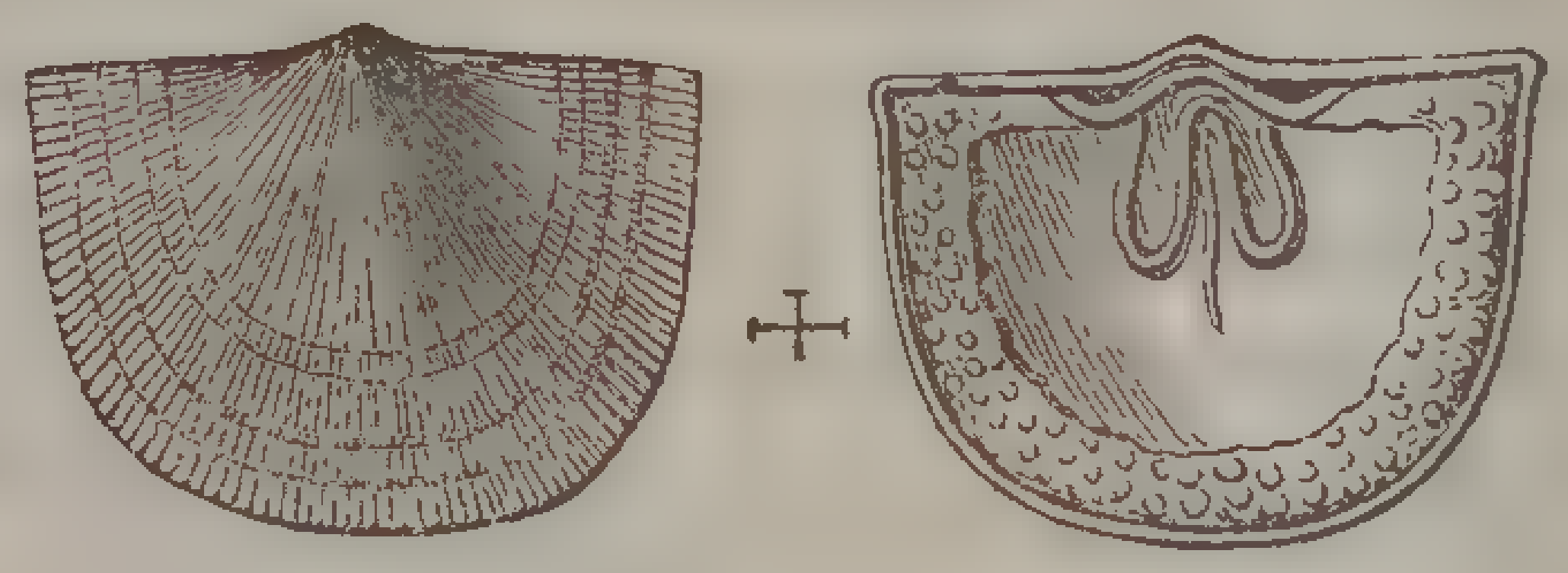
Hippopodium ponderosum, Sow.
½ diam. Lias, Cheltenham

Fig. 403.



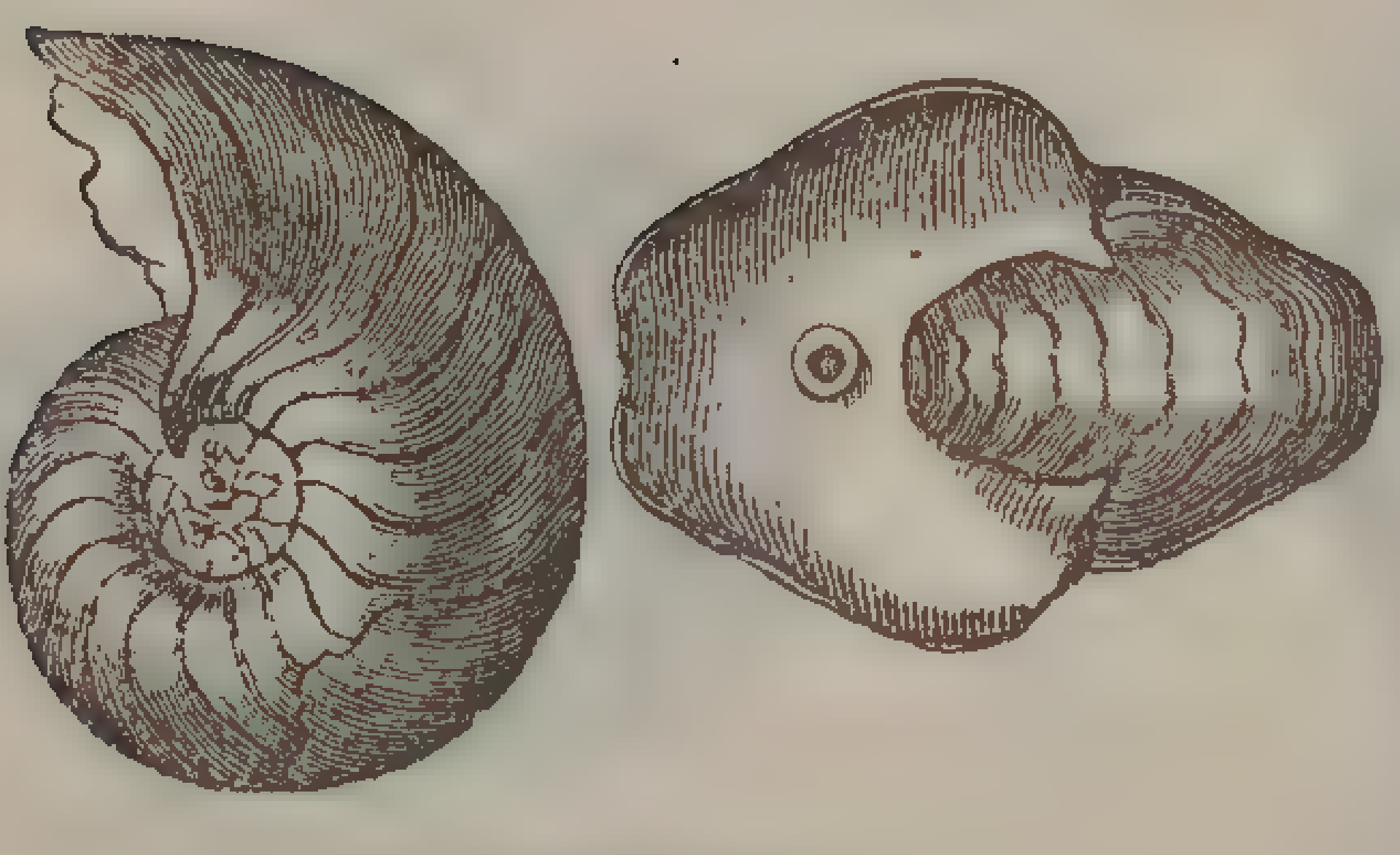
Spirifer Walcotii, Sow.
Lower Lias.

Fig. 404.



Leptæna Moorei, Dav.
Upper Lias, Ilminster.

Fig. 405.



Nautilus truncatus. Lias.

Fig. 406.

Ammonites Nodotianus?
A. striatulus, Sow.
Lias.

Fig. 407.

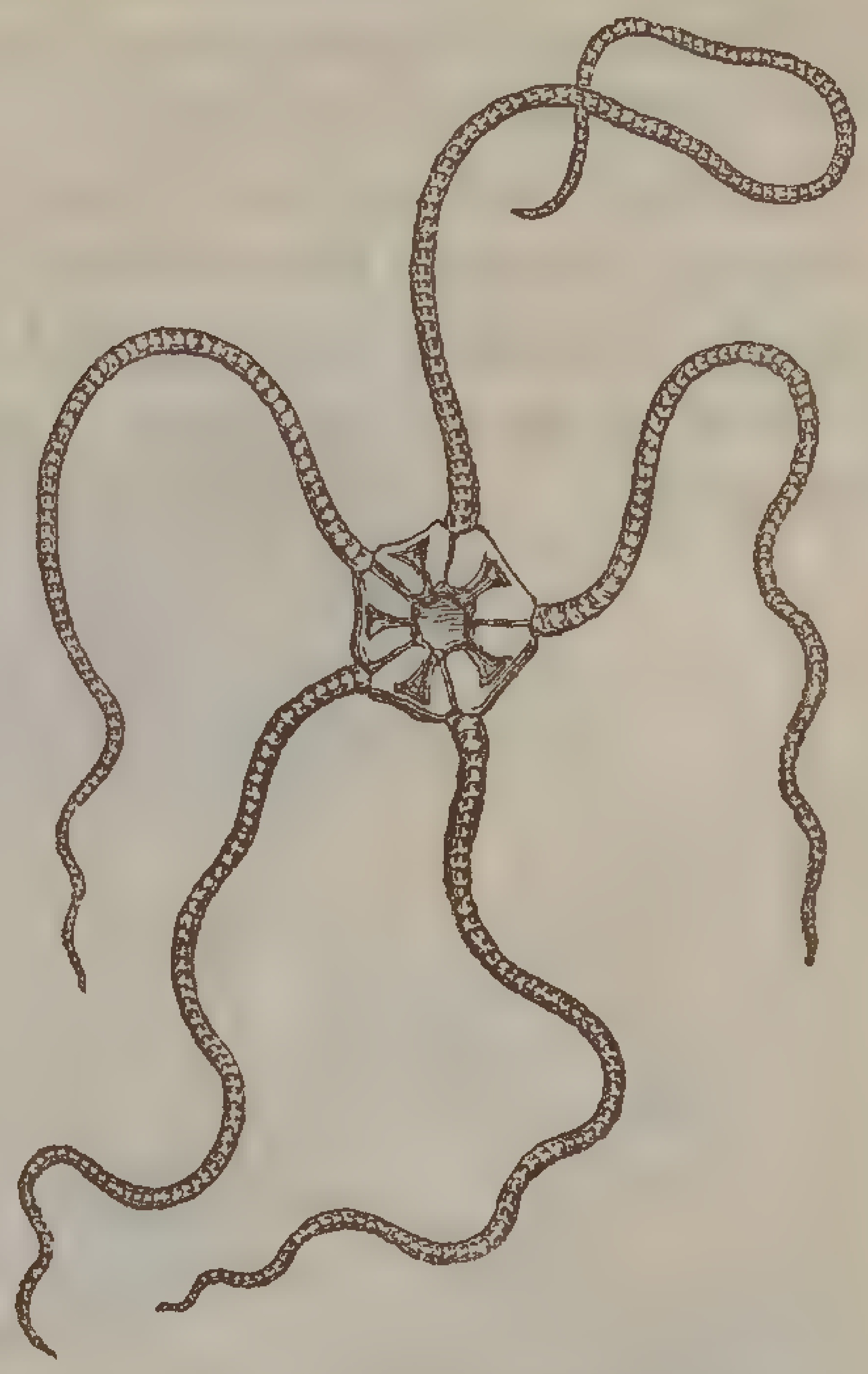
Ammonites bifrons, Brug.
A. Walcotii, Sow.
Upper Lias shales.

Briareus (fig. 408.) is conspicuous. Of *Ophioderma Egertoni* (fig. 409.), referable to the *Ophiuræ* of Müller, perfect specimens have been met with in the marlstone beds of Dorset and Yorkshire.

Fig. 408.

Extracrinus Briareus. ½ nat. size.
(Body, arms, and part of stem.)
Lias, Lyme Regis.

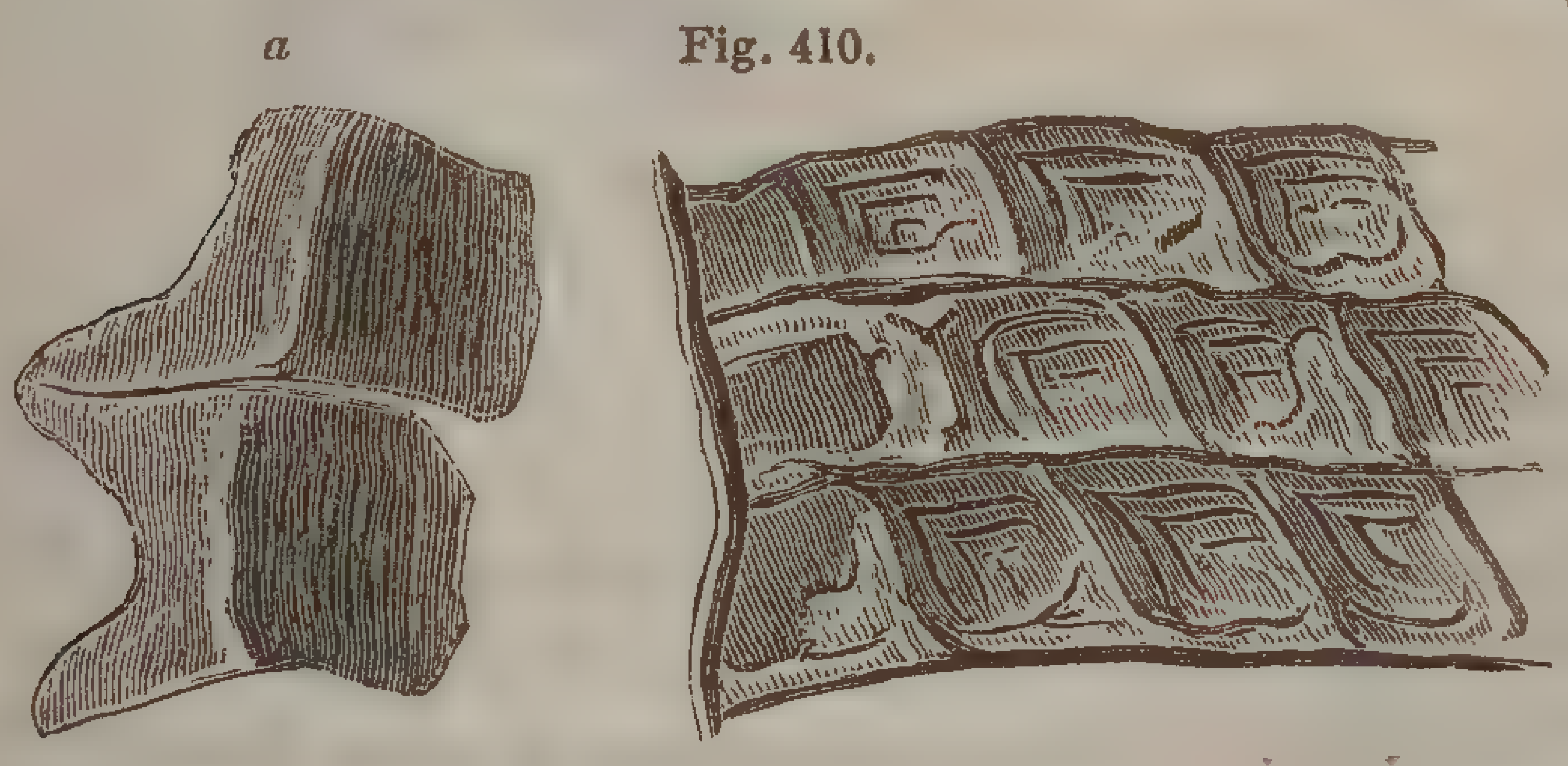
Fig. 409.



Ophioderma Egertoni, E. Forbes.
Lias Marlstone, Lyme Regis.

The *Extracrinus Briareus* (removed by Major Austin from *Pentacrinus* on account of generic differences) occurs in tangled masses, forming thin beds of considerable extent, in the lias of Dorset, Gloucestershire, and Yorkshire. The remains are often highly charged with pyrites. This Crinoid, with its innumerable tentacular arms, appears to have been frequently attached to the driftwood of the liassic sea, in the same manner as Barnacles float about at the present day. There is another species of *Extracrinus* and several of *Pentacrinus* in the lias; and the latter genus is found in nearly all the formations from the lias to the London clay inclusive. It is represented in the present seas by the delicate and rare *Pentacrinus Caput-medusæ* of the Antilles; and this indeed is perhaps the only surviving member of the great and ancient family of the Crinoids, so widely represented throughout the older formations by the genera *Taxocrinus*, *Actinocrinus*, *Cyathocrinus*, *Encrinus*, *Apiocrinus*, and many others.

Fig. 410.

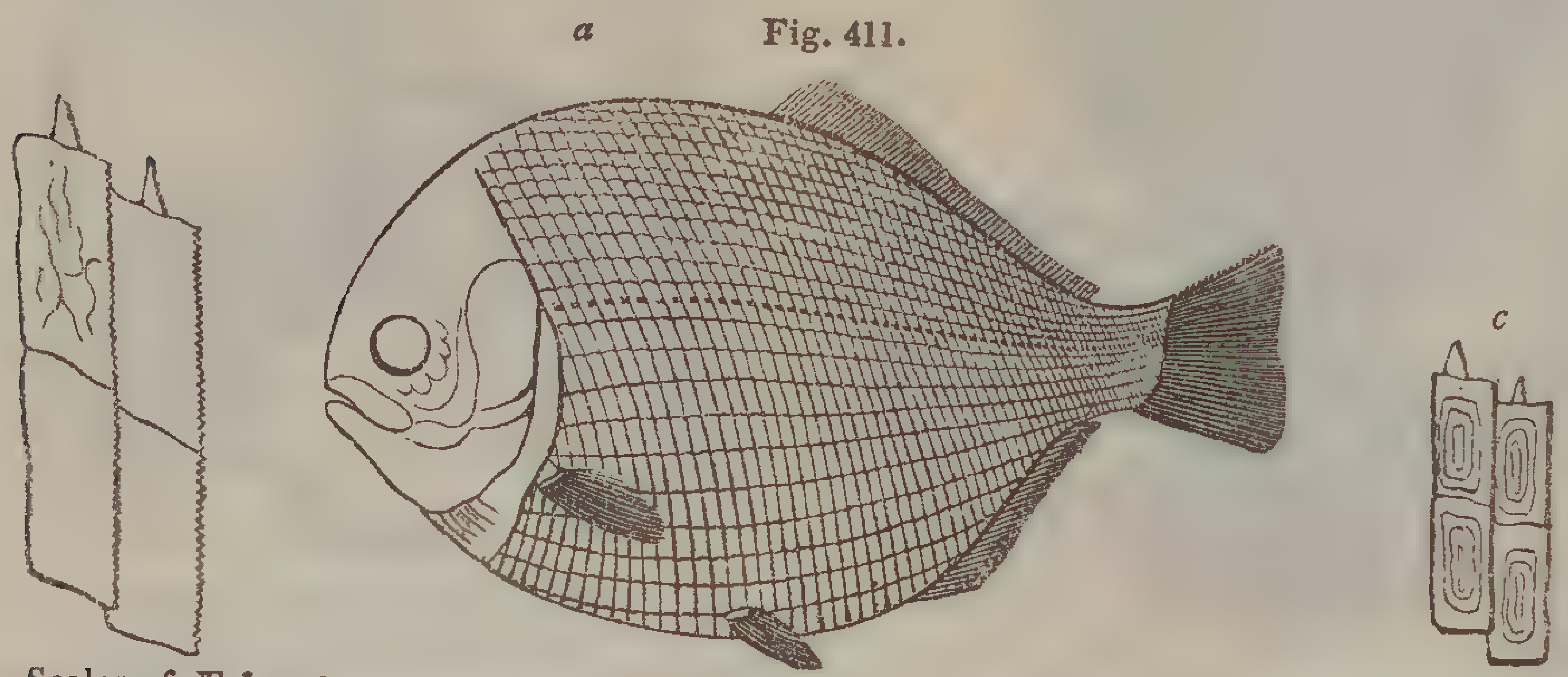


Scales of *Lepidotus gigas.* Agas.
a. Two of the scales detached.

The fossil fish resemble generically those of the oolite, belonging all, according to M. Agassiz, to extinct genera, and differing for the most part from the ichthyolites of the Cretaceous period.

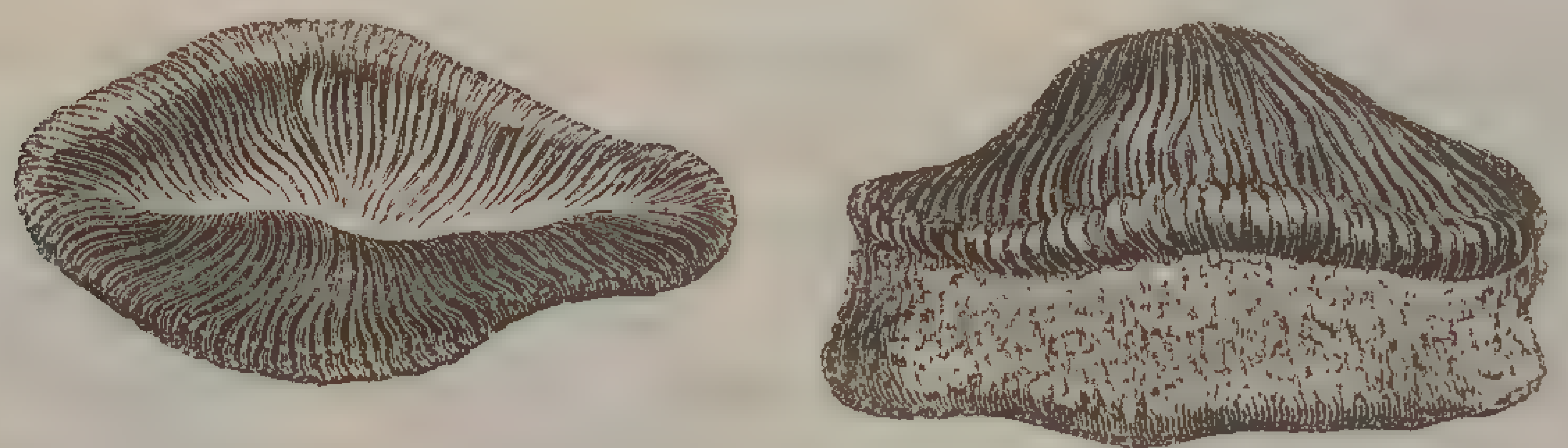
Among them is a species of *Lepidotus* (*L. gigas*, Agas.), fig. 410., which is found in the lias of England, France, and Germany.* This genus was before mentioned (p. 263.) as occurring in the Wealden, and is supposed to have frequented both rivers and coasts. Another genus of Ganoids (or fish with hard, shining, and enamelled scales), called *Æchmodus* (see fig. 411.), is almost exclusively Liassic. The teeth of a species of *Acrodus*, also, are very abundant in the lias (fig. 412.).

Fig. 411.



b. Scales of *Æchmodus Leachii*.
a. *Æchmodus*. Restored outline.
c. Scales of *Dapedius monilifer*.

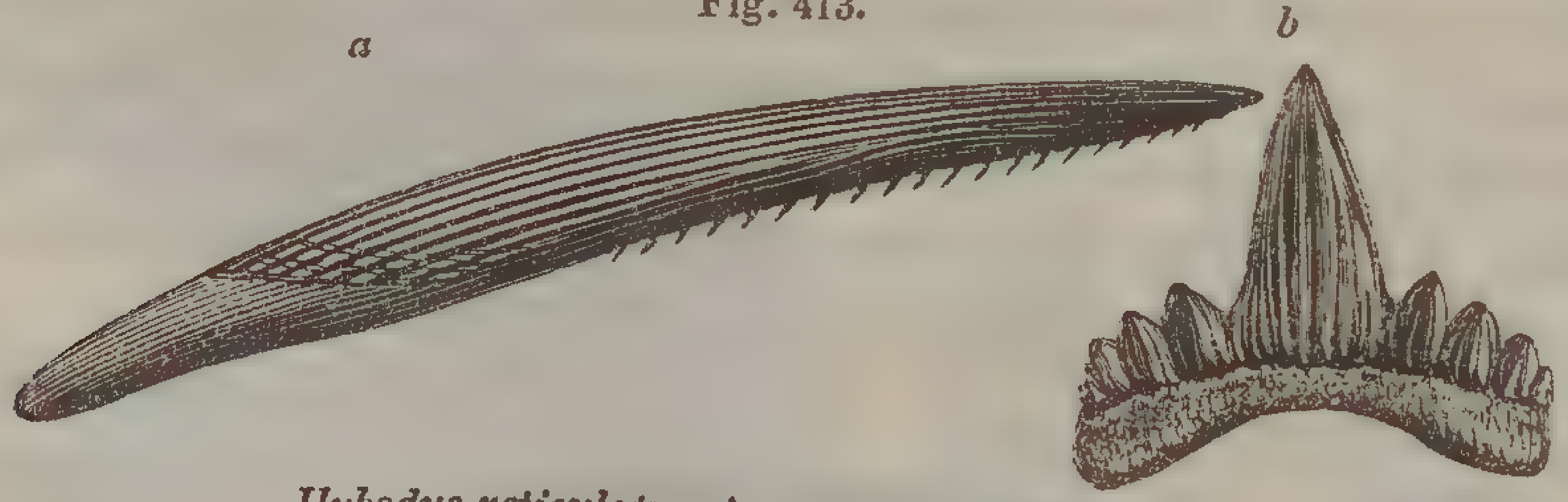
Fig. 412.



Acrodus nobilis, Agas. (tooth); commonly called "fossil leech."
Lias, Lyme Regis and Germany.

But the remains of fish which have excited more attention than any others are those large bony spines called *ichthyodorulites* (*a*, fig. 413.), which were once supposed by some naturalists to be jaws, and by others, weapons resembling those of the living *Balistes* and *Silurus;* but which M. Agassiz has shown to be neither the one nor the other. The spines, in the genera last mentioned, articulate with the backbone, whereas there are no signs of any such articulation in the ichthyodorulites. These last appear to have been bony

Fig. 413.



Hybodus reticulatus, Agas. Lias, Lyme Regis.
a. Part of fin, commonly called Ichthyodorulite.
b. Tooth.

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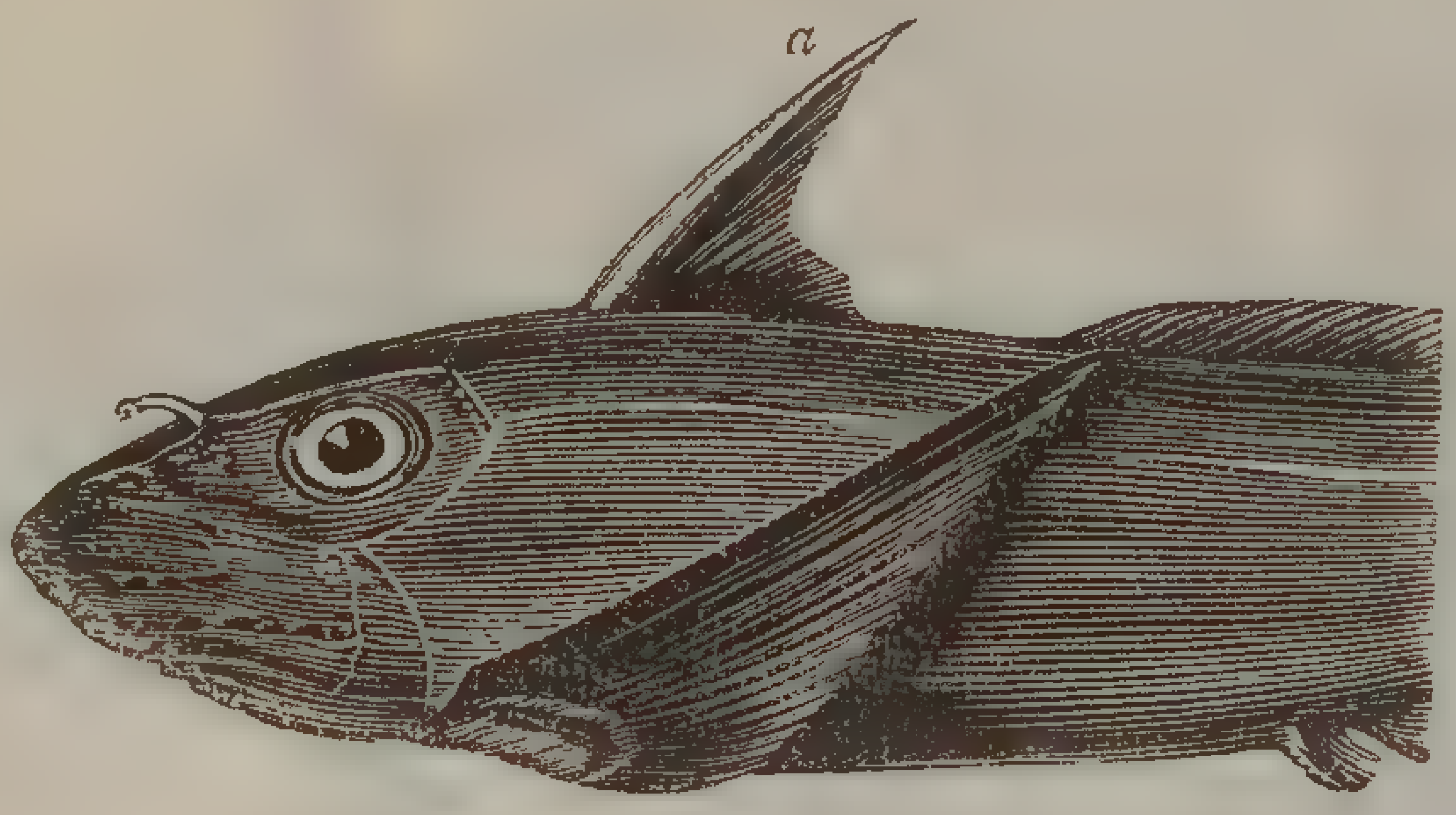
* Agassiz, Pois. Fos. vol. ii. tab. 28, 29.

spines which formed the anterior part of the dorsal fin, like that of the living genera *Cestracion* and *Chimæra* (see *a*, fig. 414.). In both of these genera, the posterior concave face is armed with small spines, as in that of the fossil *Hybodus* (fig. 413.), one of the shark family found fossil at Lyme Regis. Such spines are simply imbedded in the flesh, and attached to strong muscles. "They serve," says Dr. Buckland, "as in the *Chimæra* (fig. 414.), to raise and depress the fin, their action resembling that of a moveable mast, raising and lowering backwards the sail of a barge."†

Fig. 414.



*Chimæra monstrosa.**
a. Spine forming anterior part of the dorsal fin.

Reptiles of the Lias. — It is not, however, the fossil fish which form the most striking feature in the organic remains of the Lias; but the reptiles, which are extraordinary for their number, size, and structure. Among the most singular of these are several species of *Ichthyosaurus* and *Plesiosaurus* (figs. 415, 416.). The genus *Ichthyosaurus*, or fish-lizard, is not confined to this formation, but has been found in strata as high as the lower chalk of England, and as low as the trias of Germany, a formation which immediately succeeds the lias in the descending order.‡ It is evident from their fish-like vertebræ, their paddles, resembling those of a porpoise or whale, the length of their tail, and other parts of their structure, that the habits of the Ichthyosaurs were aquatic. Their jaws and teeth show that they were carnivorous; and the half-digested remains of fishes and reptiles, found within their skeletons, indicate the precise nature of their food.§

A specimen of the hinder fin or paddle of *Ichthyosaurus communis* was discovered in 1840 at Barrow-on-Soar, by Sir P. Egerton, which distinctly exhibits on its posterior margin the remains of cartilaginous rays that bifurcate as they approach the edge, like those in the fin of a fish. (See *a*, fig. 417.) It had previously been supposed, says Prof. Owen, that the locomotive organs of the Ichthyosaurus were enveloped, while living, in a smooth integument, like that of the turtle and porpoise, which has no other support than is afforded by the bones and ligaments within; but it now appears that the fin was much larger, expanding far beyond its osseous framework, and

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[*] Agassiz, Poissons Fossiles, vol. iii. tab. C fig. 1.

[†] Bridgewater Treatise, p. 290.

[‡] Ibid. p. 168.

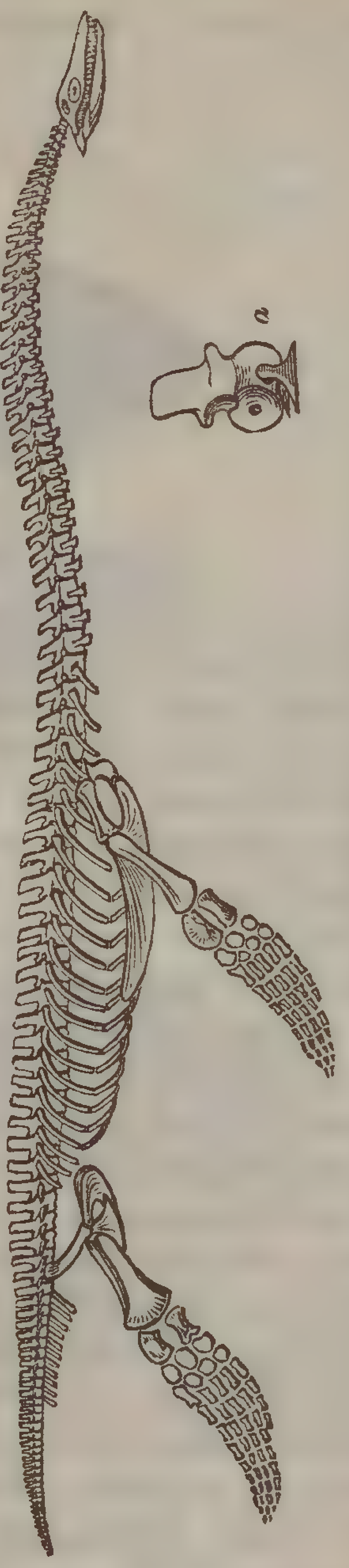
[§] Ibid. p. 187.

Fig. 415.

Skeleton of *Ichthyosaurus communis*, restored by Conybeare and Cuvier.

a. costal vertebræ.

Fig. 416.



Skeleton of *Plesiosaurus dolichodeirus*, restored by Rev. W. D. Conybeare.

a. cervical vertebra.

deviating widely in its fish-like rays from the ordinary reptilian type. In fig. 417. the posterior bones, or digital ossicles of the paddle, are seen near *b*; and beyond these is the dark carbonized integument of the terminal half of the fin, the outline of which is beautifully defined.* Prof. Owen believes that, besides the fore-paddles, these short- and stiff-necked saurians were furnished with a tail-fin without radiating bones, and purely tegumentary, expanding in a vertical direction; an organ of motion which enabled them to turn their heads rapidly.†

Mr. Conybeare was enabled, in 1824, after examining many skele-

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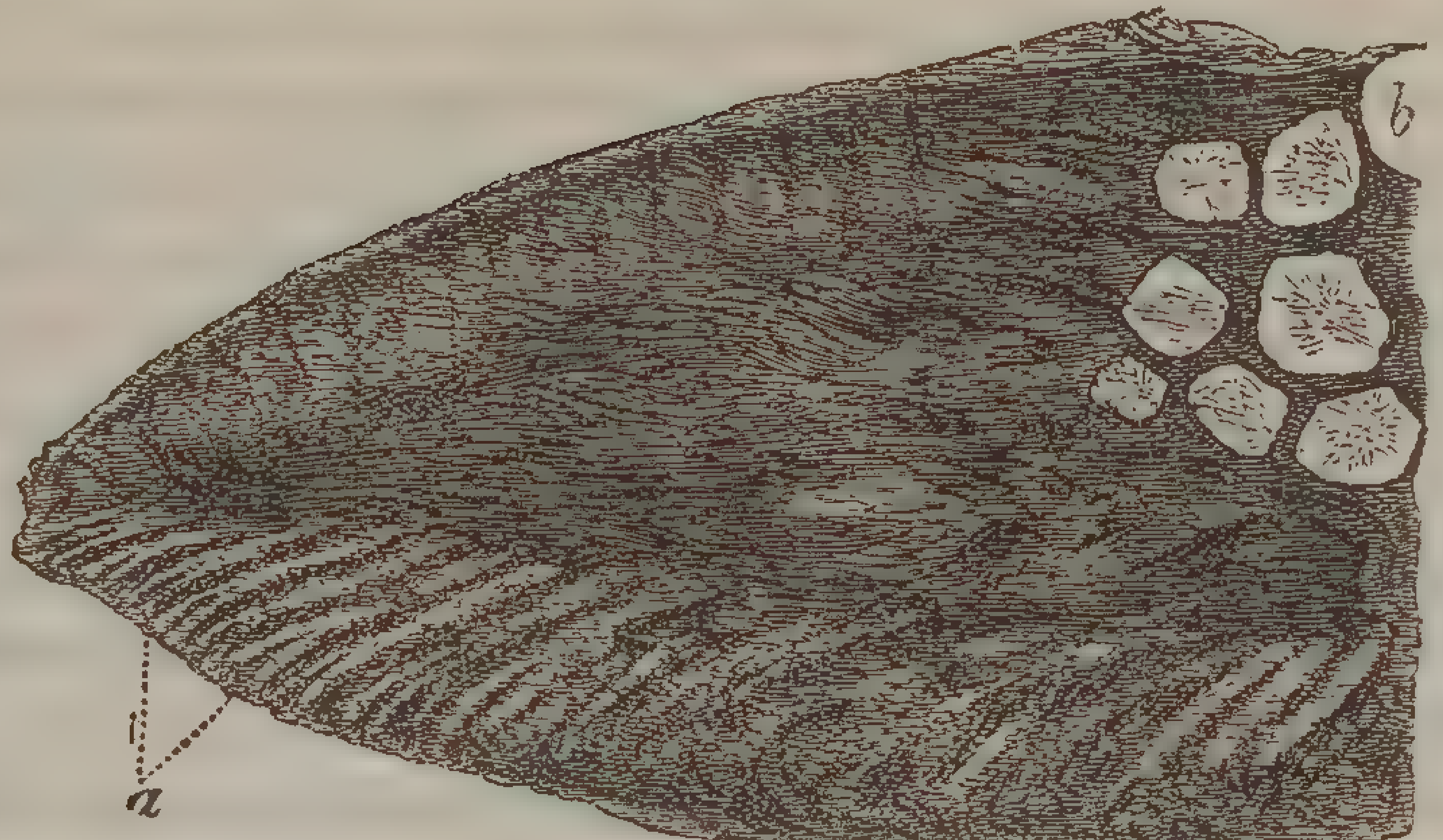
* Geol. Soc. Transact. Second Series, vol. vi. p. 199. pl. xx.

† Geol. Soc. Trans. Second Series, vol. v. p. 511.

Fig. 417.



Posterior part of hind fin or paddle of *Ichthyosaurus communis.*

tons nearly perfect, to give an ideal restoration of the osteology of this genus, and of that of the *Plesiosaurus.** (See figs. 415, 416.) The latter animal had an extremely long neck and small head, with teeth like those of the crocodile, and paddles analogous to those of the *Ichthyosaurus,* but larger. It is supposed to have lived in shallow seas and estuaries, and to have breathed air like the Ichthyosaur and our modern cetacea.† Some of the reptiles above mentioned were of formidable dimensions. One specimen of *Ichthyosaurus platyodon,* from the lias at Lyme, now in the British Museum, must have belonged to an animal more than 24 feet in length; and another of the *Plesiosaurus,* in the same collection, is 11 feet long. The form of the *Ichthyosaurus* may have fitted it to cut through the waves like the porpoise; but it is supposed that the *Plesiosaurus,* at least the long-necked species (fig. 416.), was better suited to fish in shallow creeks and bays defended from heavy breakers.

In many specimens both of Ichthyosaur and Plesiosaur the bones of the head, neck, and tail are in their natural position, while those of the rest of the skeleton are detached and in confusion. Mr. Stutchburg has suggested that their bodies after death became inflated with gases, and, while the abdominal viscera were decomposing, the bones, though disunited, were retained within the tough dermal covering as in a bag, until the whole, becoming water-logged, sank to the bottom.‡ As they belonged to individuals of all ages they are supposed, by Dr. Buckland, to have experienced a violent death; and the same conclusion might also be drawn from their having escaped the attacks of their own predacious race, or of fishes, found fossil in the same beds.

For the last twenty years, anatomists have agreed that these extinct saurians must have inhabited the sea; and it was urged that, as there are now chelonians, like the tortoise, living in fresh water, and others, as the turtle, frequenting the ocean, so there may have

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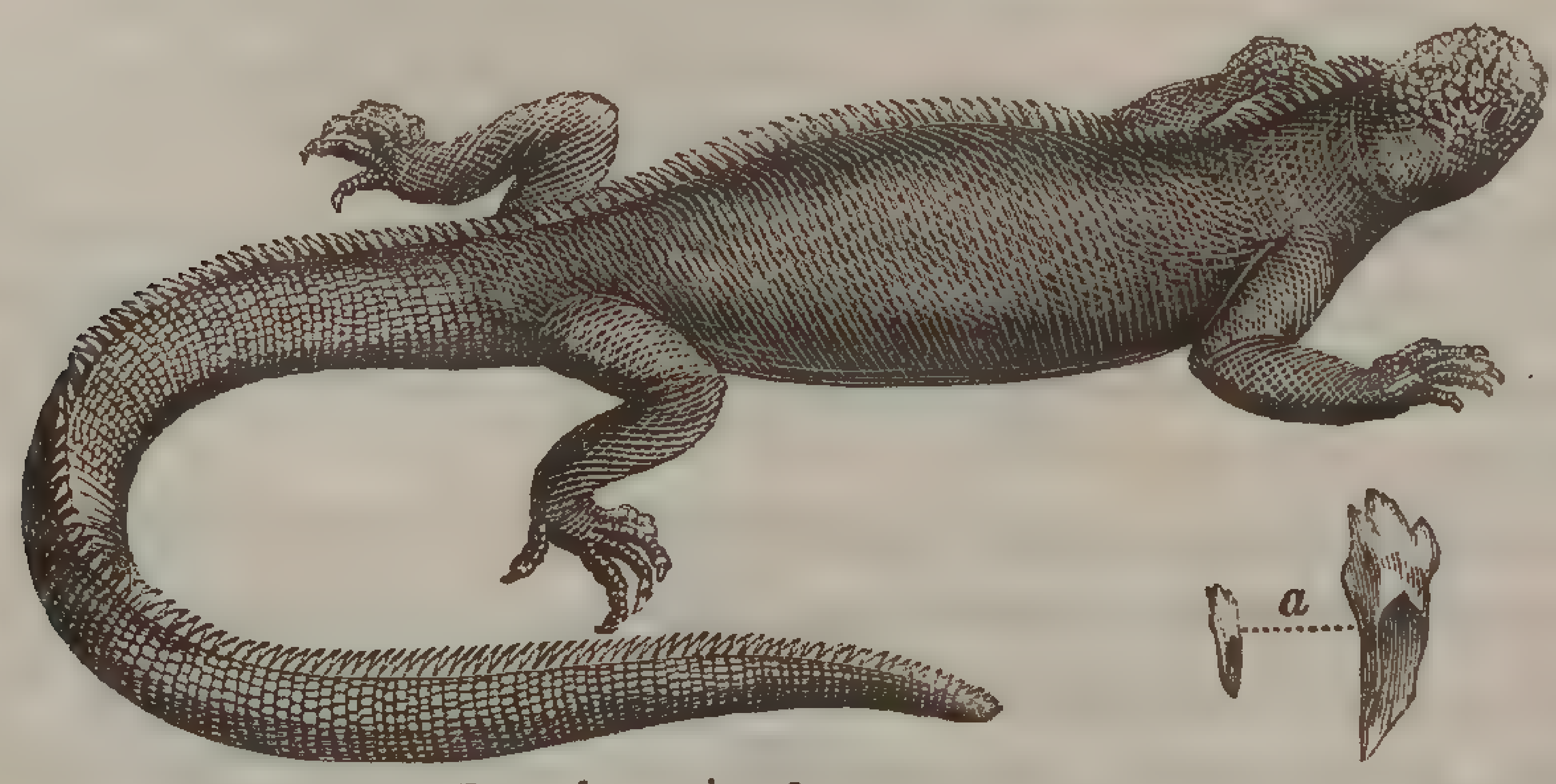
* Geol. Trans., Second Series, vol. i. pl. 49.

† Conybeare and De la Beche. Geol. Trans. 1st Ser. vol. v. p. 559.; and Buckland, Bridgew. Treat., p. 203.

‡ Quart. Geol. Journ. vol. ii. p. 411.

been formerly some saurians proper to salt, others to fresh water. The common crocodile of the Ganges is well known to frequent equally that river and the brackish and salt water near its mouth; and crocodiles are said in like manner to be abundant both in the rivers of the Isla de Pinos (or Isle of Pines), south of Cuba, and in the open sea round the coast. More recently a saurian has been discovered of aquatic habits and exclusively marine. This creature was found in the Galapagos Islands, during the visit of H. M. S. Beagle to that archipelago, in 1835, and its habits were then observed by Mr. Darwin. The islands alluded to are situated under the equator, nearly 600 miles to the westward of the coast of South America. They are volcanic; some of them being 3000 or 4000 feet high; and one of them, Albemarle Island, 75 miles long. The climate is mild; very little rain falls; and, in the whole archipelago, there is only one rill of fresh water that reaches the coast. The soil is for the most part dry and harsh, and the vegetation scanty. The birds, reptiles, plants, and insects are, with very few exceptions, of species found no where else in the world, although all partake, in their general form, of a South American type. Of the mammalia, says Mr. Darwin, one species alone appears to be indigenous, namely, a large and peculiar kind of mouse; but the number of lizards, tortoises, and snakes is so great, that it may be called a land of reptiles. The variety, indeed, of species is small; but the individuals of each are in wonderful abundance. There is a turtle, a large tortoise (*Testudo Indicus*), four lizards, and about the same number of snakes, but no frogs or toads. Two of the lizards belong to the family *Iguanidæ* of Bell, and to a peculiar genus (*Amblyrhynchus*) established by that naturalist, and so named from their obtusely truncated head and short snout.* Of these lizards one is terrestrial in its habits, and burrows in the ground, swarming everywhere on the land, having a round tail, and a mouth somewhat resembling in form that of the tortoise. The other is aquatic, and has its tail flattened laterally for swimming (see fig. 418.) "This marine saurian," says Mr. Darwin, "is extremely common on all the islands throughout

Fig. 418.



Amblyrhynchus cristatus, Bell. Length varying from 3 to 4 feet. The only existing marine lizard now known.

a. Tooth, natural size and magnified.

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* Αμϐλυς, *amblys*, blunt; and ῥυγχος, *rhynchus*, snout.

the archipelago. It lives exclusively on the rocky sea-beaches, and I never saw one even ten yards inshore. The usual length is about a yard, but there are some even 4 feet long. It is of a dirty black colour, sluggish in its movements on the land; but, when in the water, it swims with perfect ease and quickness by a serpentine movement of its body and flattened tail, the legs during this time being motionless, and closely collapsed on its sides. Their limbs and strong claws are admirably adapted for crawling over the rugged and fissured masses of lava which everywhere form the coast. In such situations, a group of six or seven of these hideous reptiles may oftentimes be seen on the black rocks, a few feet above the surf, basking in the sun with outstretched legs. Their stomachs, on being opened, were found to be largely distended with minced sea-weed, of a kind which grows at the bottom of the sea at some little distance from the coast. To obtain this, the lizards go out to sea in shoals. One of these animals was sunk in salt water, from the ship, with a heavy weight attached to it, and on being drawn up again after an hour it was quite active and unharmed. It is not yet known by the inhabitants where this animal lays its eggs; a singular fact, considering its abundance, and that the natives are well acquainted with the eggs of the terrestrial *Amblyrhynchus,* which is also herbivorous." *

In those deposits now forming by the sediment washed away from the wasting shores of the Galapagos Islands the remains of saurians, both of the land and sea, as well as of chelonians and fish, may be mingled with marine shells, without any bones of land quadrupeds or batrachian reptiles; yet even here we should expect the remains of marine mammalia to be imbedded in the new strata, for there are seals, besides several kinds of cetacea, on the Galapagian shores; and, in this respect, the parallel between the modern fauna, above described, and the ancient one of the lias would not hold good.

Sudden destruction of saurians. — It has been remarked, and truly, that many of the fish and saurians, found fossil in the lias, must have met with sudden death and immediate burial; and that the destructive operation, whatever may have been its nature, was often repeated.

"Sometimes," says Dr. Buckland, "scarcely a single bone or scale has been removed from the place it occupied during life; which could not have happened had the uncovered bodies of these saurians been left, even for a few hours, exposed to putrefaction, and to the attacks of fishes, and other smaller animals at the bottom of the sea."† Not only are the skeletons of the Ichthyosaurs entire, but sometimes the contents of their stomachs still remain between their ribs, as before remarked, so that we can discover the particular species of fish on which they lived, and the form of their excrements. Not unfrequently there are layers of these coprolites, at different depths in the lias, at a distance from any entire skeletons of the marine lizards

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* Darwin's Journal, chap. xix.

† Bridgew. Treat., p. 125.

from which they were derived; "as if," says Sir H. de la Beche, "the muddy bottom of the sea received small sudden accessions of matter from time to time, covering up the coprolites and other exuviæ which had accumulated during the intervals."* It is farther stated that, at Lyme Regis, those surfaces only of the coprolites which lay uppermost at the bottom of the sea have suffered partial decay, from the action of water before they were covered and protected by the muddy sediment that has afterwards permanently enveloped them.†

Numerous specimens of the Calamary or pen-and-ink fish (*Geoteuthis Bollensis*, Schuble sp.) have also been met with in the lias at Lyme, with the ink-bags still distended, containing the ink in a dried state, chiefly composed of carbon, and but slightly impregnated with carbonate of lime. These cephalopoda, therefore, must, like the saurians, have been soon buried in sediment; for, if long exposed after death, the membrane containing the ink would have decayed.‡

As we know that river-fish are sometimes stifled, even in their own element, by muddy water during floods, it cannot be doubted that the periodical discharge of large bodies of turbid fresh water into the sea may be still more fatal to marine tribes. In the "Principles of Geology" I have shown that large quantities of mud and drowned animals have been swept down into the sea by rivers during earthquakes, as in Java, in 1699; and that undescribable multitudes of dead fishes have been seen floating on the sea after a discharge of noxious vapours during similar convulsions.§ But, in the intervals between such catastrophes, strata may have accumulated slowly in the sea of the lias, some being formed chiefly of one description of shell, such as ammonites, others of gryphites.

From the above remarks the reader will infer that the lias is for the most part a marine deposit. Some members, however, of the series, especially in the lowest part of it, have an estuary character, and must have been formed within the influence of rivers. In Gloucestershire, where there is a good type of the lias of the West of England, it has been divided into an upper mass of shale with a base of marlstone, and a lower series of shales with underlying limestones and shales. We learn from the researches of the Rev. P. B. Brodie‖, that in the superior of these two divisions numerous remains of insects and plants have been detected in several places, mingled with marine shells; but in the inferior division similar fossils are still more plentiful. One band, rarely exceeding a foot in thickness, has been named the "insect limestone." It passes upwards into a shale containing *Cypris* and *Estheria*, and is charged with the wing-cases of several genera of coleoptera, and with some nearly entire beetles, of which the eyes are preserved. The nervures of the wings of neurop-

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* Geological Researches, p. 334.

† Buckland, Bridgew. Treat., p. 307.

‡ Ibid.

§ See Principles, *Index*, Lancerote, Graham Island, Calabria.

‖ A History of Fossil Insects, &c. 1846. London.

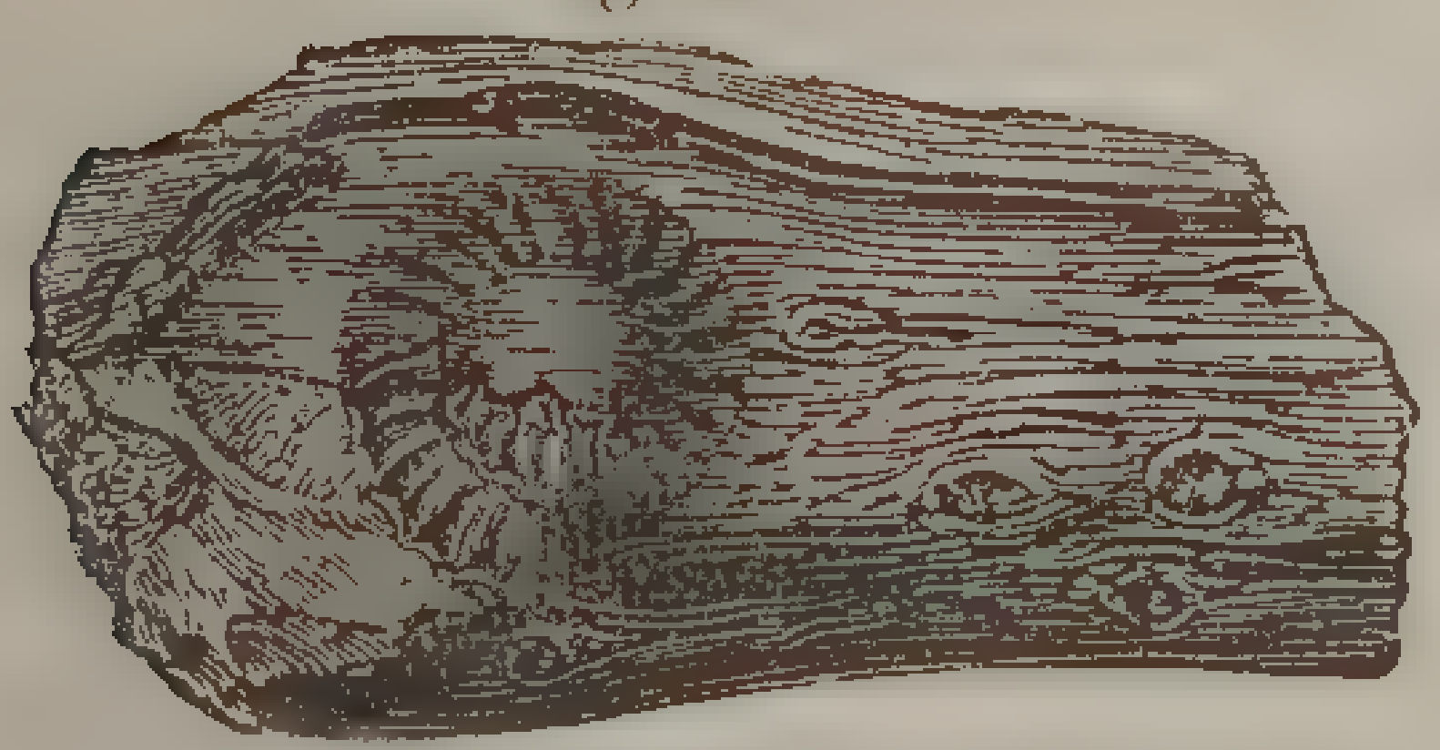
Fig. 419.

Wing of a neuropterous insect, from the Lower Lias, Gloucestershire. (Rev. P. B. Brodie.)

terous insects (fig. 419.) are beautifully perfect in this bed. Ferns, with leaves of monocotyledonous plants, and some apparently brackish and freshwater shells, accompany the insects in several places, while in others marine shells predominate, the fossils varying apparently as we examine the bed nearer or farther from the ancient land, or the source whence the fresh water was derived. There are two, or even three, bands of "insect limestone" in several sections, and they have been ascertained by Mr. Brodie to retain the same lithological and zoological characters when traced from the centre of Warwickshire to the borders of the southern part of Wales. After studying 300 specimens of these insects from the lias, Mr. Westwood declares that they comprise both wood-eating and herb-devouring beetles of the Linnean genera *Elater*, *Carabus*, &c., besides grasshoppers (*Gryllus*), and detached wings of dragon-flies and may-flies, or insects referable to the Linnean genera *Libellula*, *Ephemera*, *Hemerobius*, and *Panorpa*, in all belonging to no less than twenty-four families. The size of the species is usually small, and such as taken alone would imply a temperate climate; but many of the associated organic remains of other classes must lead to a different conclusion.

Fossil plants.—Among the vegetable remains of the Lias, several species of *Zamia* have been found at Lyme Regis, and the remains of coniferous plants at Whitby. Fragments of wood are common, and often converted into limestone. That some of this wood, though now petrified, was soft when it first lay at the bottom of the sea, is shown by a specimen now in the museum of the Geological Society (see fig. 420.), which has the form of an *ammonite* indented on its surface.

Fig. 420.



M. Ad. Brongniart enumerates forty-seven liassic acrogens, most of them ferns; and fifty gymnogens, of which thirty-nine are cycads, and eleven conifers. Among the cycads the predominance of *Zamites* and *Nilssonia*, and among the ferns the numerous genera with leaves having reticulated veins (as in fig. 385. p. 315.), are mentioned as botanical characteristics of this era.* The absence as yet from the Lias and Ooolite of all signs of dicotyledonous angiosperms is worthy of notice. The leaves of such plants are frequent in tertiary strata, and occur in the Cretaceous, though less plentifully (see above, p. 267.) The angiosperms seem, therefore, to have been at the least comparatively rare in these older secondary periods, when more space was occupied by the Cycads and Conifers.

Origin of the Oolite and Lias.—If we now endeavour to restore, in imagination, the ancient condition of the European area at the

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* Tableau des Vég. Fos. 1849, p. 105.

period of the Oolite and Lias, we must conceive a sea in which the growth of coral-reefs and shelly limestones, after proceeding without interruption for ages, was liable to be stopped suddenly by the deposition of clayey sediment. Then, again, the argillaceous matter, devoid of corals, was deposited for ages, and attained a thickness of hundreds of feet, until another period arrived when the same space was again occupied by calcareous sand, or solid rocks of shell and coral, to be again succeeded by the recurrence of another period of argillaceous deposition. Mr. Conybeare has remarked of the entire group of Oolite and Lias, that it consists of repeated alternations of clay, sandstone, and limestone, following each other in the same order. Thus the clays of the lias are followed by the sands of the inferior oolite, and these again by shelly and coralline limestone (Bath oolite, &c.); so, in the middle oolite, the Oxford clay is followed by calcareous grit and coral rag; lastly, in the upper oolite, the Kimmeridge clay is followed by the Portland sand and limestone.* The clay beds, however, as Sir H. De la Beche remarks, can be followed over larger areas than the sands or sandstones.† It should also be remembered that while the oolitic system becomes arenaceous and resembles a coal-field in Yorkshire, it assumes in the Alps an almost purely calcareous form, the sands and clays being omitted; and even in the intervening tracts it is more complicated and variable than appears in ordinary descriptions. Nevertheless, some of the clays and intervening limestones do retain, in reality, a pretty uniform character for distances of from 400 to 600 miles from east to west and north to south.

According to M. Thirria, the entire oolitic group in the department of the Haute Saône, in France, may be equal in thickness to that of England; but the importance of the argillaceous divisions is in the inverse ratio to that which they exhibit in England, where they are about equal to twice the thickness of the limestones, whereas, in the part of France alluded to, they reach only about a third of that thickness.‡ In the Jura the clays are still thinner; and in the Alps they thin out and almost vanish.

In order to account for such a succession of events, we may imagine, first, the bed of the ocean to be the receptacle for ages of fine argillaceous sediment, brought by oceanic currents, which may have communicated with rivers, or with part of the sea near a wasting coast. This mud ceases, at length, to be conveyed to the same region, either because the land which had previously suffered denudation is depressed and submerged, or because the current is deflected in another direction by the altered shape of the bed of the ocean and neighbouring dry land. By such changes the water becomes once more clear and fit for the growth of stony zoophytes. Calcareous sand is then formed from comminuted shell and coral, or, in some cases, arenaceous matter replaces the clay; because it commonly

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* Con. and Phil., p. 166.

† Geol. Researches, p. 337.

‡ Burat's D'Aubuisson, tom. ii. p. 456.

happens that the finer sediment, being first drifted farthest from coasts, is subsequently overspread by coarse sand, after the sea has grown shallower, or when the land, increasing in extent, whether by upheaval or by sediment filling up parts of the sea, has approached nearer to the spots first occupied by fine mud.

In order to account for another great formation, like the Oxford clay, again covering one of coral limestone, we must suppose a sinking down like that which is now taking place in some existing regions of coral between Australia and South America. The occurrence of subsidences, on so vast a scale, may have caused the bed of the ocean and the adjoining land, throughout great parts of the European area, to assume a shape favourable to the deposition of another set of clayey strata; and this change may have been succeeded by a series of events analogous to that already explained, and these again by a third series in similar order. Both the ascending and descending movements may have been extremely slow, like those now going on in the Pacific; and the growth of every stratum of coral, a few feet of thickness, may have required centuries for its completion, during which certain species of organic beings disappeared from the earth, and others were introduced in their place; so that, in each set of strata, from the Lias to the Upper Oolite, some peculiar and characteristic fossils were embedded.

Oolite and Lias of the United States.

There are large tracts on the globe, as in Russia and the United States, where all the members of the oolitic series are unrepresented. In the state of Virginia, however, at the distance of about 13 miles eastward of Richmond, the capital of that State, there is a regular coal-field occurring in a depression of the granite rocks (see section, fig. 421.), which Professor W. B. Rogers first correctly referred to the age of the lower part of the Jurassic group. This opinion I was enabled to confirm after collecting a large number of fossil plants, fish, and shells, and examining the coal-field throughout its whole area. It extends 26 miles from north to south, and from 4 to 12, from east to west. The plants consist chiefly of zamites, calamites, and equisetums, and these last are very commonly met with in

Fig. 421.

Section showing the geological position of the James River, or East Virginian Coal-field.

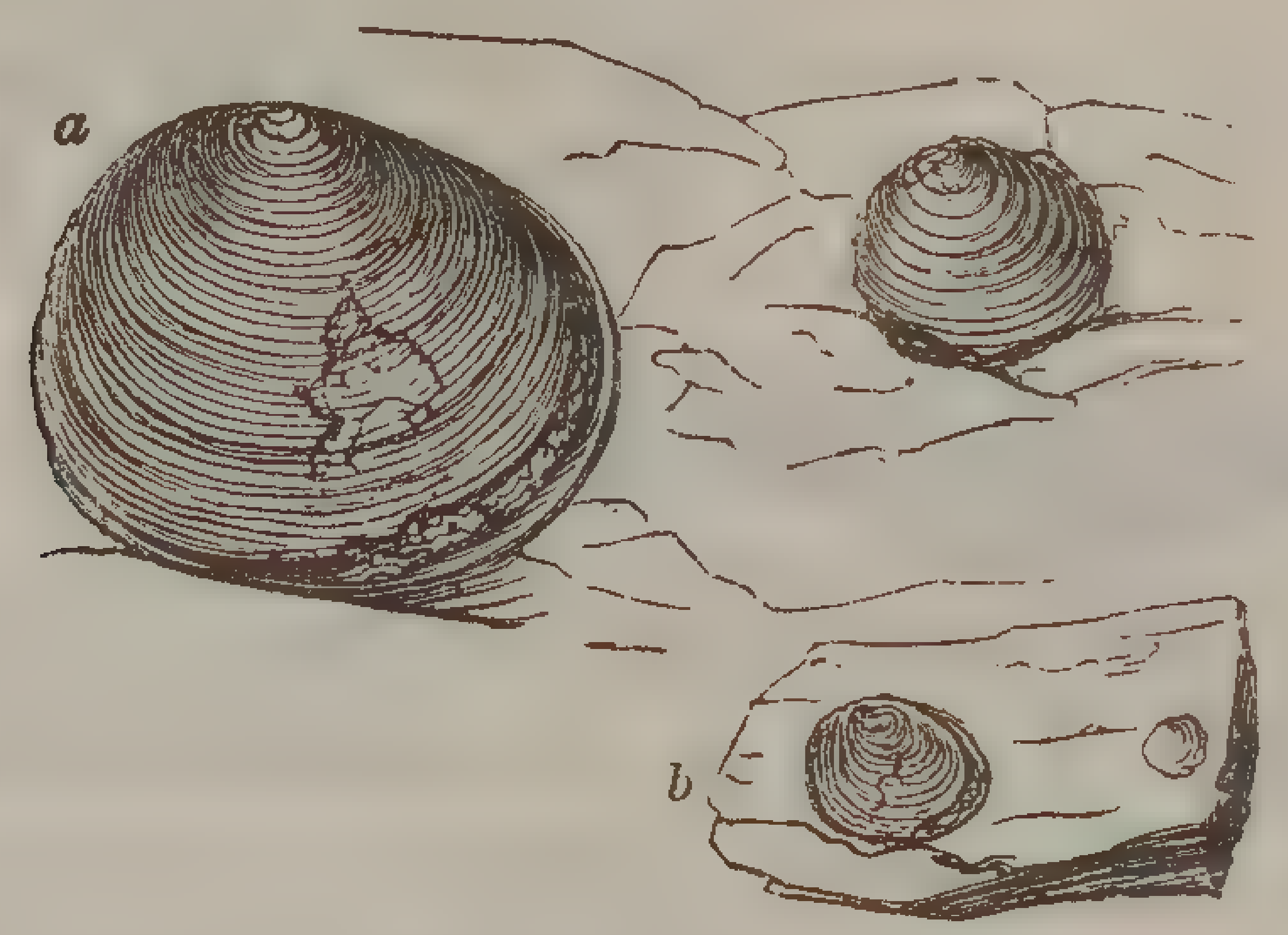
A. Granite, gneiss, &c.
B. Coal-measures.
C. Tertiary strata.
D. Drift or *ancient alluvium.*

a vertical position more or less compressed perpendicularly. It is clear that they grew in the places where they are now buried in strata of hardened sand and mud. I found them maintaining their erect attitude, at points many miles distant from others, in beds both above and between the seams of coal. In order to explain this fact we must suppose such shales and sandstones to have been gradually accumulated during the slow and repeated subsidence of the whole region.

It is worthy of remark that the *Equisetum columnare* of these Virginian rocks appears to be undistinguishable from the species found in the oolitic sandstones near Whitby in Yorkshire, where it also is met with in an upright position. One of the Virginian fossil ferns, *Pecopteris Whitbyensis*, is also a species common to the Yorkshire oolites.* These Virginian coal-measures are composed of grits, sandstones, and shales, exactly resembling those of older or primary date in America and Europe, and they rival or even surpass the latter in the richness and thickness of the coal-seams. One of these, the main seam, is in some places from 30 to 40 feet thick, composed of pure bituminous coal. On descending a shaft 800 feet deep, in the Blackheath mines in Chesterfield county, I found myself in a chamber more than 40 feet high, caused by the removal of this coal. Timber props of great strength supported the roof, but they were seen to bend under the incumbent weight. The coal is like the finest kinds shipped at Newcastle, and when analysed yields the same proportions of carbon and hydrogen, a fact worthy of notice when we consider that this fuel has been derived from an assemblage of plants very distinct specifically, and in part generically, from those which have contributed to the formation of the ancient or paleozoic coal.

The fossil fish of these Richmond strata belong to the liassic genus *Tetragonolepis* (*Æchmodus*), see fig. 411., and to a new genus which I have called *Dictyopyge*. Shells are very rare, as usually in all

Fig. 422.



a. Posidonomya or *Estheria.*? † *b.* Young of same.
Oolitic coal-shale, Richmond, Virginia.

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* See description of the coal-field by the author, and of the plants by C. J. F. Bunbury, Esq., Quart. Geol. Journ., vol. iii. p. 281.

† Possibly, as suggested by Prof. Morris (Geol. Journ. vol. iii. p. 275.), these delicate bivalves may prove to belong to the crustacean genus *Estheria*.

coal-bearing deposits, but a species of *Posidonomya* is in such profusion in some shaly beds as to divide them like the plates of mica in micaceous shales (see fig. 422.).

In India, especially in Cutch, a formation occurs clearly referable to the oolitic and liassic type, as shown by the shells, corals, and plants; and there also coal has been procured from one member of the group.

CHAPTER XXII.

TRIAS OR NEW RED SANDSTONE GROUP.

Distinction between New and Old Red Sandstone — Between Upper and Lower New Red — The Trias and its three divisions — Most largely developed in Germany — Keuper and its fossils — Muschelkalk and fossils — Fossil plants of the Bunter — Triassic group in England — Bone-bed of Axmouth and Aust — Red Sandstone of Warwickshire and Cheshire — Footsteps of *Cheirotherium* in England and Germany — Osteology of the *Labyrinthodon* — Identification of this Batrachian with the Cheirotherium — Triassic mammifer — Origin of Red Sandstone and Rock-salt — Hypothesis of saline volcanic exhalations — Theory of the precipitation of salt from inland lakes or lagoons — Saltness of the Red Sea — New Red Sandstone in the United States — Fossil footprints of birds and reptiles in the valley of the Connecticut — Antiquity of the Red Sandstone containing them.

BETWEEN the Lias and the Coal (or Carboniferous group) there is interposed, in the midland and western counties of England, a great series of red loams, shales, and sandstones, to which the name of the "New Red Sandstone formation" was first given, to distinguish it from other shales and sandstones called the "Old Red" (*c.* fig. 423.), often identical in mineral character, which lie immediately beneath the coal (*b*).

Fig. 423.

a. New red sandstone. *b.* Coal. *c.* Old red.

The name of "Red Marl" has been incorrectly applied to the red clays of this formation, as before explained (p. 13.), for they are remarkably free from calcareous matter. The absence, indeed, of carbonate of lime, as well as the scarcity of organic remains, together with the bright red colour of most of the rocks of this group, causes a strong contrast between it and the Jurassic formations before described.

Before the distinctness of the fossil remains characterizing the upper and lower part of the English New Red had been clearly recognized, it was found convenient to have a common name for all the strata intermediate in position between the Lias and Coal; and the term "Poikilitic" was proposed by Messrs. Conybeare and Buckland*, from ποικιλος, poikilos, *variegated*, some of the most characteristic strata of this group having been called *variegated* by

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* Buckland, Bridg. Treat., vol. ii. p. 38.

Werner, from their exhibiting spots and streaks of light-blue, green, and buff colour, in a red base.

A single term, thus comprehending both Upper and Lower New Red, or the Triassic and Permian groups of modern classifications, may still be useful in describing districts where we have to speak of masses of red sandstone and shale, referable, in part, to both these eras, but which, in the absence of fossils, it is impossible to divide.

TRIAS OR UPPER NEW RED SANDSTONE GROUP.

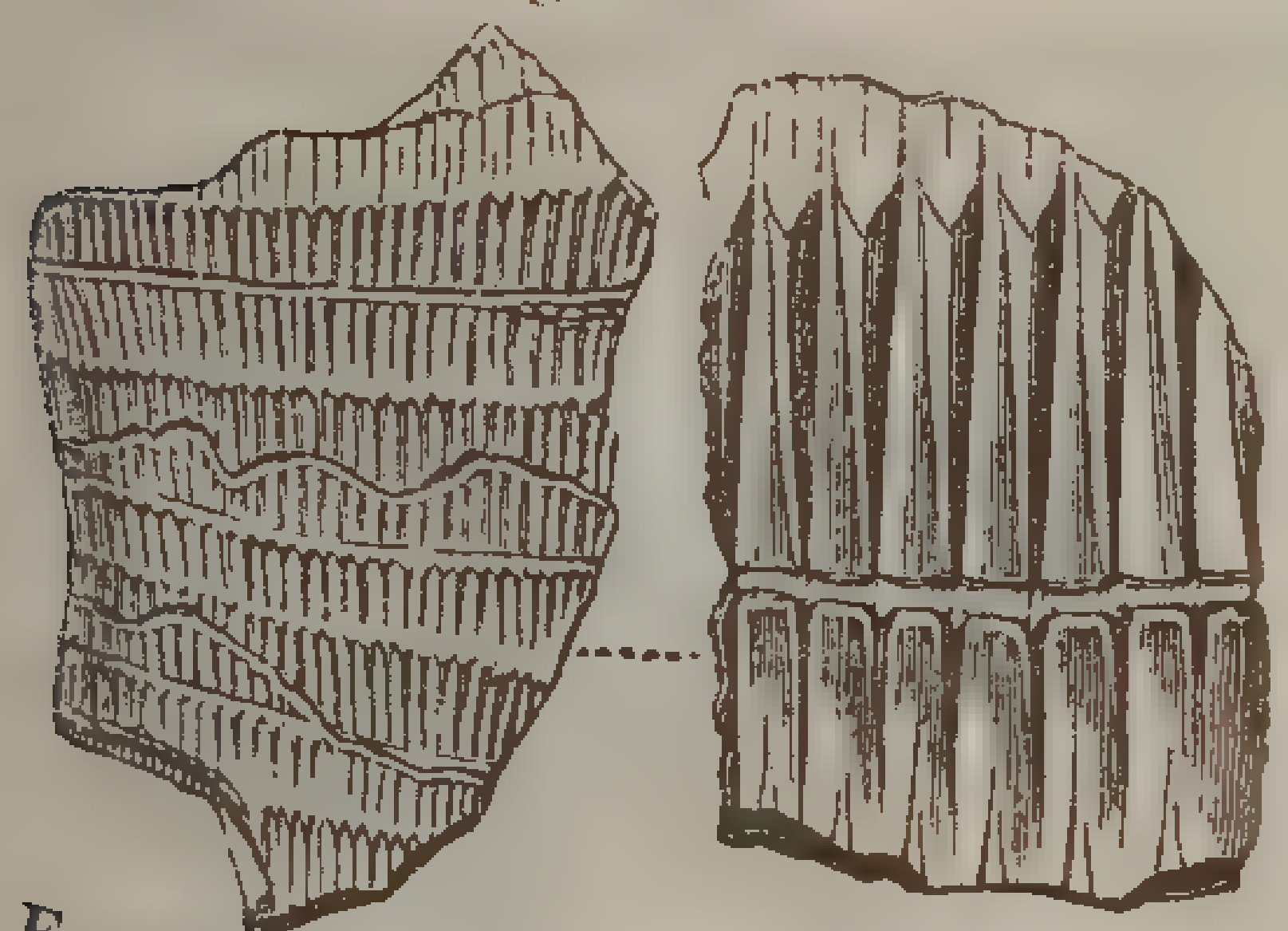
The accompanying table will explain the subdivisions generally adopted for the uppermost of the two systems above alluded to, and the names given to them in England and on the Continent.

		Synonyms.	
		German.	French.
Trias or Upper New Red Sandstone -	*a.* Saliferous and gypseous shales and sandstone - -	Keuper -	Marnes irisées.
	b. (wanting in England)	Muschelkalk -	Muschelkalk, ou calcaire coquillier.
	c. Sandstone and quartzose conglomerate -	Bunter-sandstein - -	Grès bigarré.

I shall first describe this group as it occurs in South-western and North-western Germany, for it is far more fully developed there than in England or France. It has been called the Trias by German writers, or the Triple Group, because it is separable into three distinct formations, called the "Keuper," the "Muschelkalk," and the "Bunter-sandstein."

The Keuper, the first or newest of these, is 1000 feet thick in Würtemberg, and is divided by Alberti into sandstone, gypsum, and carbonaceous slate-clay.* Remains of Reptiles, called *Nothosaurus* and *Phytosaurus*, have been found in it with *Labyrinthodon;* the detached teeth, also, of placoid fish and of rays, and of the genera *Saurichthys* and *Gyrolepis* (figs. 433, 434., p. 338.). The plants of the Keuper are generically very analogous to those of the lias and oolite, consisting of ferns, equisetaceous plants, cycads, and conifers, with a few doubtful monocotyledons. A few species, such as *Equisetites columnaris*, are common to this group and the oolite.

Fig. 424.



Equisetites columnaris. (Syn. *Equisetum columnare.*) Fragment of stem, and a small portion of same magnified. Keuper.

The Muschelkalk consists chiefly of a compact, greyish limestone, but includes beds of dolomite in many places, together with gypsum and rock-salt. This limestone, a rock wholly unrepresented in England, abounds in fossil shells, as the name implies. Among the cephalopoda there are no belemnites, and no ammonites with foliated sutures, as in the incumbent lias and oolite, but a genus allied to the Ammonite, called *Ceratites* by De Haan, in which the descending

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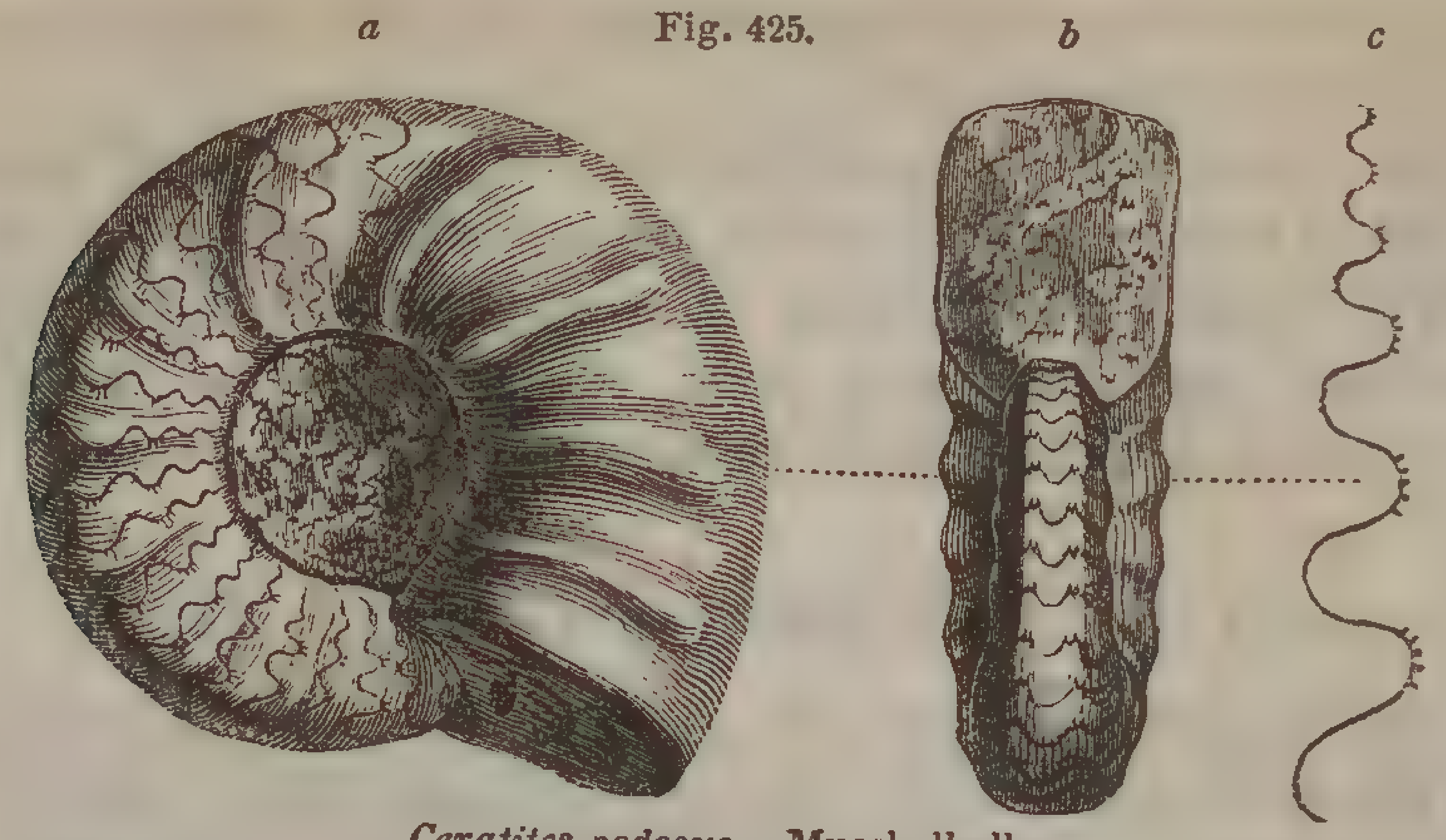
* Monog. des Bunten Sandsteins.

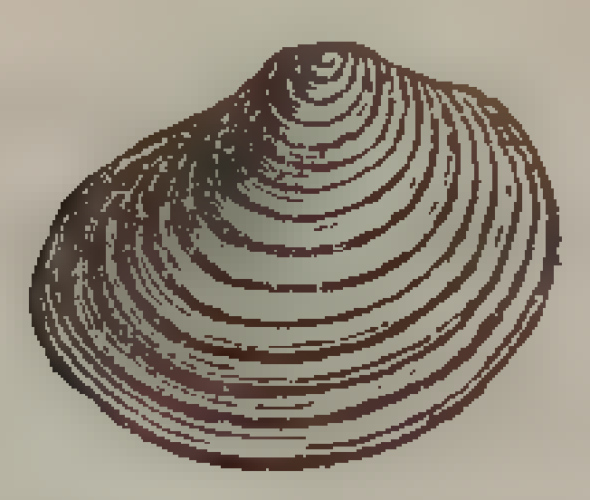
Fig. 425.



Ceratites nodosus. Muschelkalk.
a. Side view. *b.* Front view.
c. Partially denticulated outline of the septa dividing the chambers.

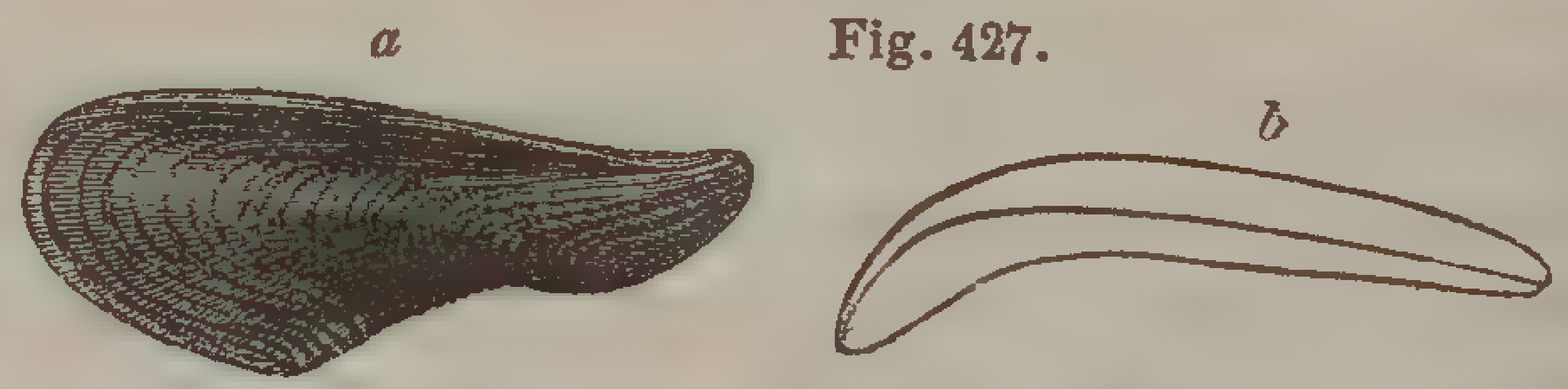
lobes (see *a, b, c*, fig. 425.) terminate in a few small denticulations pointing inwards. Among the bivalve shells, the *Posidonia minuta*, Goldf. (*Posidonomya minuta*, Bronn), see fig. 426., is abundant, ranging through the Keuper, Muschelkalk, and Bunter-sandstein; and *Avicula socialis*, fig. 427., having a similar range, is very characteristic of the Muschelkalk in Germany, France, and Poland.

Fig. 426.



Posidonia minuta, Goldf. (*Posidonomya minuta*, Bronn.)

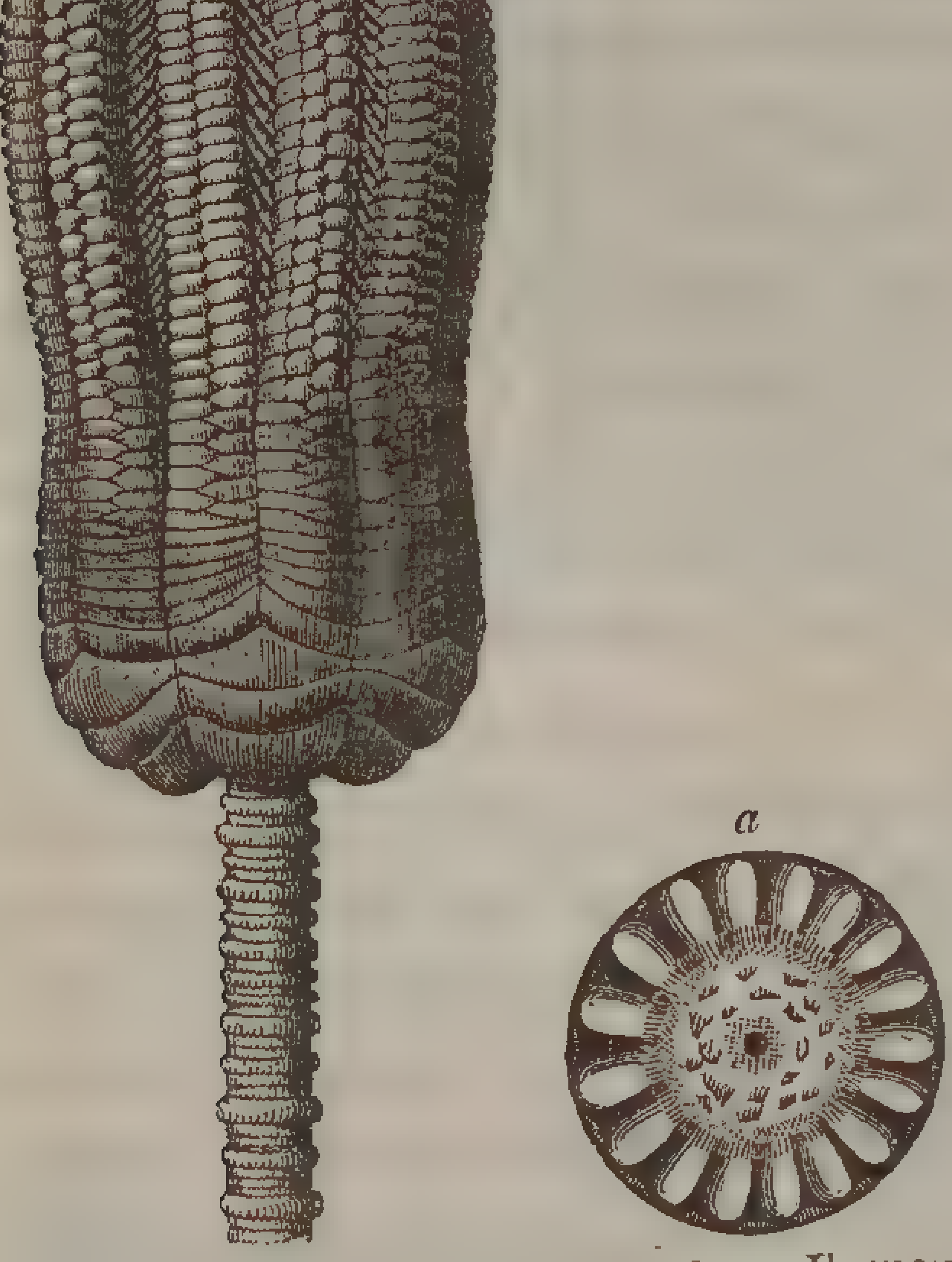
Fig. 427.



a. Avicula socialis *b.* Side view of same.
Characteristic of the Muschelkalk.

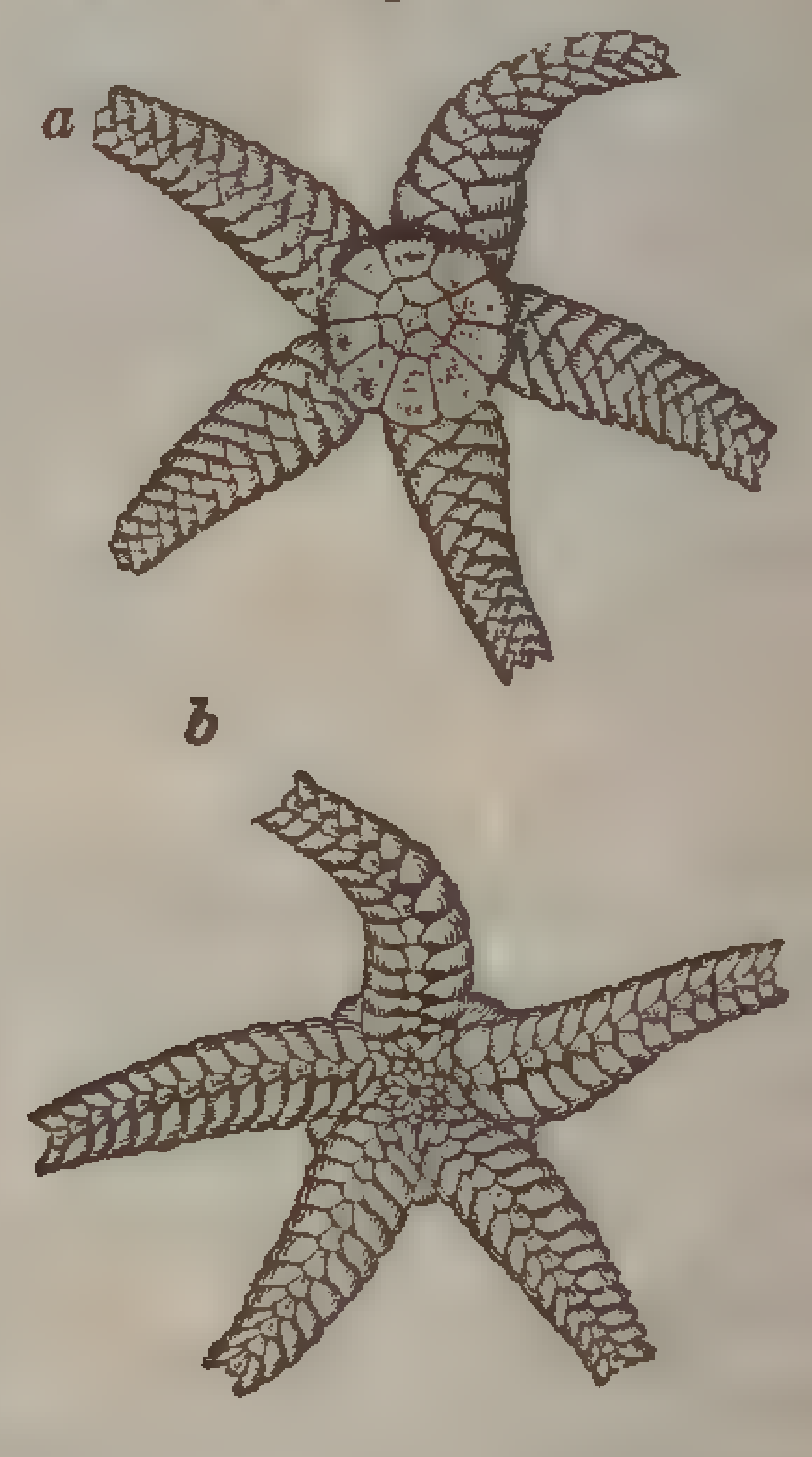
The abundance of the heads and stems of lily encrinites, *Encrinus liliiformis*, fig. 428. (or *Encrinites moniliformis*), show the slow manner in which some beds of this limestone have been formed in clear sea-water. The star-fish called *Aspidura loricata*, fig. 429.,

Fig. 428.



Encrinus liliiformis, Schlott. Syn. *E. moniliformis.*
Body, arms, and part of stem.
a. Section of stem.
Muschelkalk.

Fig. 429.



Aspidura loricata, Agas.
a. Upper side.
b. Lower side.
Muschelkalk.

is as yet peculiar to the Muschelkalk. In the same formation are found ganoid fish with heterocercal tails, of the genus *Placodus*. (See fig. 430.)

Fig. 430.

Palatal teeth of *Placodus gigas*. Muschelkalk.

Fig. 431.

a. *Voltzia heterophylla*. (Syn. *Voltzia brevifolia*.)
b. portion of same magnified to show fructification. Sulzbad. Bunter-sandstein.

The *Bunter-sandstein* consists of various coloured sandstones, dolomites, and red-clays, with some beds, especially in the Hartz, of calcareous pisolite or roe-stone, the whole sometimes attaining a thickness of more than 1000 feet. The sandstone of the Vosges, according to Von Meyer, is proved, by the presence of *Labyrinthodon*, to belong to this lowest member of the Triassic group. At Sulzbad (or Soultz-les-bains), near Strasburg, on the flanks of the Vosges, many plants have been obtained from the "bunter," especially conifers of the extinct genus *Voltzia*, peculiar to this period, in which even the fructification has been preserved. (See fig. 431.)

Out of thirty species of ferns, cycads, conifers, and other plants, enumerated by M. Ad. Brongniart, in 1849, as coming from the "gres bigarré," or Bunter, not one is common to the Keuper.* This difference, however, may arise partly from the fact that the flora of "the Bunter" has been almost entirely derived from one district (the neighbourhood of Strasburg), and its peculiarities may be local.

The footprints of a reptile (*Labyrinthodon*) have been observed on the clays of this member of the Trias, near Hildburghausen, in Saxony, impressed on the upper surface of the beds, and standing out as casts in relief from the under sides of incumbent slabs of sandstone. To these I shall again allude in the sequel; they attest, as well as the accompanying ripple-marks, and the cracks which traverse the clays, the gradual deposition of the beds of this formation in shallow water, and sometimes between high and low water.

Triassic Group in England.

In England the Lias is succeeded by conformable strata of red and green marl, or clay. There intervenes, however, both in the neighbourhood of Axmouth, in Devonshire, and in the cliffs of Westbury

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* Tableau des Genres de Vég. Fos., Dict. Univ. 1849.

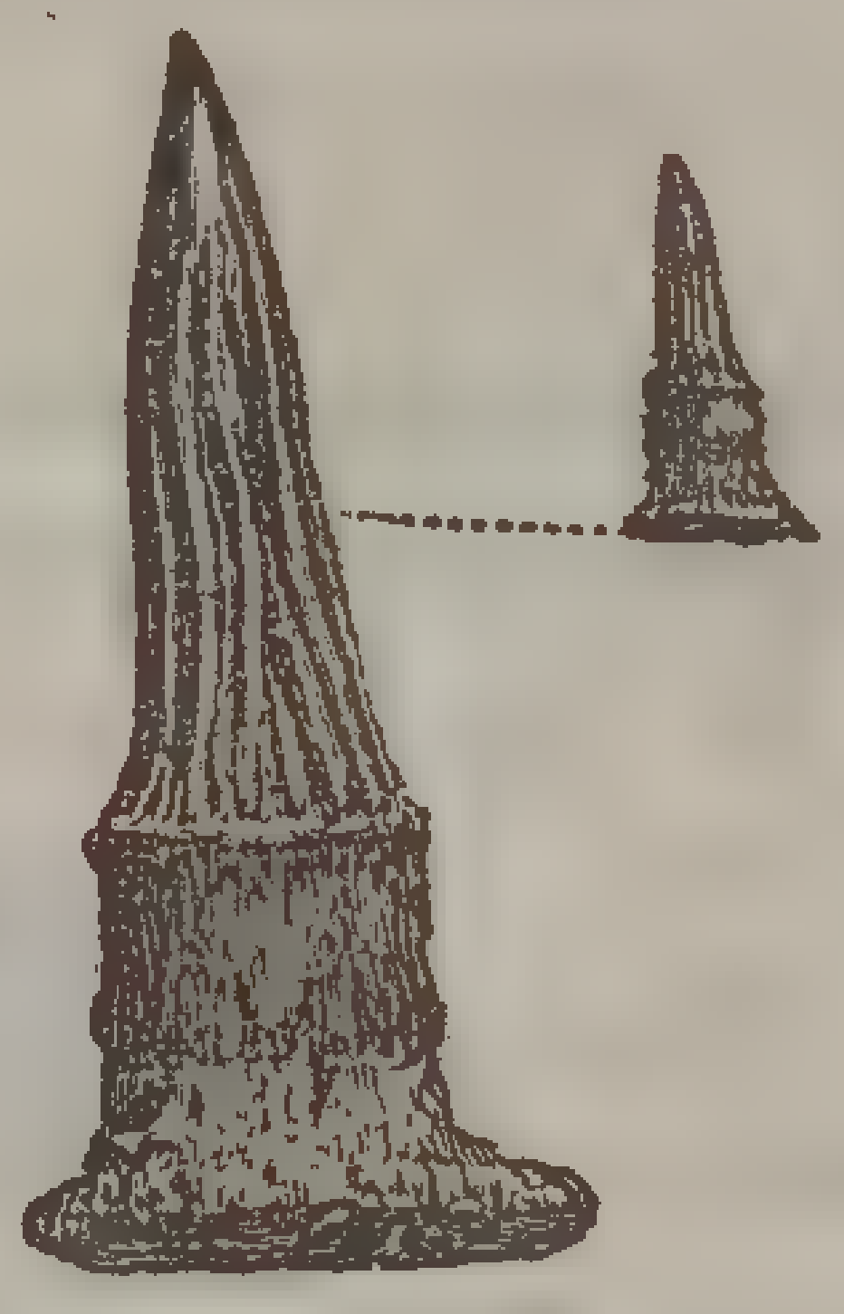
and Aust, in Gloucestershire, on the banks of the Severn, a dark-coloured stratum, well known by the name of the "bone-bed." It abounds in the remains of saurians and fish, and was formerly classed as the lowest bed of the Lias; but Sir P. Egerton has shown that it should be referred to the Upper New Red Sandstone, for it contains an assemblage of fossil fish which are either peculiar to this stratum or belong to species well known in the Muschelkalk of Germany. These fish belong to the genera *Acrodus*, *Hybodus*, *Gyrolepis*, and *Saurichthys*.

Among those common to the English bone-bed and the Muschelkalk of Germany are *Hybodus plicatilis* (fig. 432.), *Saurichthys apicalis* (fig. 433.), *Gyrolepis tenuistriatus* (fig. 434.), and *G. Albertii*. Remains of saurians have also been found in the bone-bed, and plates of an *Encrinus*.

Fig. 432.

Hybodus plicatilis. Teeth. Bone-bed, Aust and Axmouth.

Fig. 433.



Saurichthys apicalis. Tooth; nat. size, and magnified. Axmouth.

Fig. 434.

Gyrolepis tenuistriatus. Scale; nat. size, and magnified. Axmouth.

The strata of red and green marl, which follow the bone-bed in the descending order at Axmouth and Aust, are destitute of organic remains; as is the case, for the most part, in the corresponding beds in almost every part of England. But fossils have been found at a few localities in sandstones of this formation, in Worcestershire and Warwickshire, and among them the bivalve shell called *Posidonia minuta*, Goldf., before mentioned (fig. 426. p. 336.).

The upper member of the English "New Red" containing this shell, in those parts of England, is, according to Messrs. Murchison and Strickland, 600 feet thick, and consists chiefly of red marl or slate, with a band of sandstone. Ichthyodorulites, or spines of *Hybodus*, teeth of fishes, and footprints of reptiles were observed by the same geologists in these strata*; and the remains of a saurian, called *Rhynchosaurus*, have been found in this portion of the Trias at Grinsell, near Shrewsbury.

In Cheshire and Lancashire the gypseous and saliferous red shales and clays of the Trias are between 1000 and 1500 feet thick. In some places lenticular masses of rock-salt are interpolated between the argillaceous beds, the origin of which will be spoken of in the sequel.

The lower division or English representative of the "Bunter"

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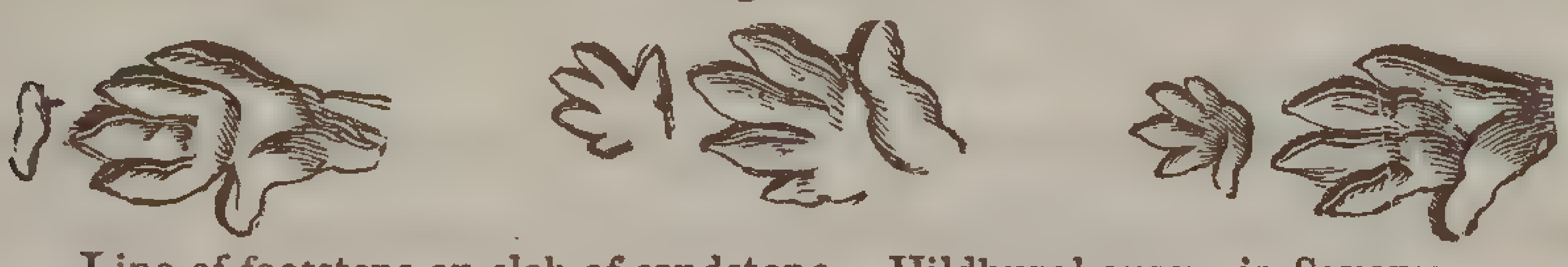
* Geol. Trans., Sec. Ser., vol. v. p. 318. &c.

attains a thickness of 600 feet in the counties last mentioned. Besides red and green shales and red sandstones, it comprises much soft white quartzose sandstone, in which the trunks of silicified trees have been met with at Allesley Hill, near Coventry. Several of them were a foot and a half in diameter, and some yards in length, decidedly of coniferous wood, and showing rings of annual growth.* Impressions, also, of the footsteps of animals have been detected in Lancashire and Cheshire in this formation. Some of the most remarkable occur a few miles from Liverpool, in the whitish quartzose sandstone of Storton Hill, on the west side of the Mersey. They bear a close resemblance to tracks first observed in a member of the Upper New Red Sandstone, at the village of Hesseberg, near Hildburghausen, in Saxony, to which I have already alluded. For many years these footprints have been referred to a large unknown quadruped, provisionally named *Cheirotherium* by Professor Kaup, because the marks both of the fore and hind feet resembled impressions made by a human hand. (See fig. 435.) The footmarks at Hesseberg are partly concave, and partly in relief; the former, or the depressions, are seen upon the upper surface of the sandstone slabs, but those in relief are only upon the lower surfaces, being in fact natural casts, formed in the subjacent footprints as in moulds. The larger impressions, which seem to be those of the hind foot, are generally 8 inches in length, and 5 in width, and one was 12 inches long. Near each large footstep, and at a regular distance (about an inch and a half), before it, a smaller print of a fore foot, 4 inches long and 3 inches wide, occurs. The footsteps follow each other in pairs, each pair in the same line, at intervals of 14 inches from pair to pair. The large as well as the small steps show the great toes alternately on the right and left side; each step makes the print of five toes, the first or great toe being bent inwards like a thumb. Though the fore and hind foot differ so much in size, they are nearly similar in form.

Fig. 435.

Single footstep of *Cheirotherium*. Bunter Sandstein, Saxony; one eighth of nat. size.

Fig. 436.



Line of footsteps on slab of sandstone. Hildburghausen, in Saxony.

The similar footmarks afterwards observed in a rock of corresponding age at Storton Hill were imprinted on five thin beds of clay, superimposed one upon the other in the same quarry, and separated by beds of sandstone. On the lower surface of the sandstone

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* Buckland, Proc. Geol. Soc. vol. ii. p. 439.; and Murchison and Strickland, Geol. Trans., Second Ser., vol. v. p. 347.

strata, the solid casts of each impression are salient, in high relief, and afford models of the feet, toes, and claws of the animals which trod on the clay. On the same surfaces Mr. J. Cunningham discovered (1839) distinct casts of rain-drop markings.

As neither in Germany nor in England any bones or teeth had been met with in the same identical strata as the footsteps, anatomists indulged, for several years, in various conjectures respecting the mysterious animals from which they might have been derived. Professor Kaup suggested that the unknown quadruped might have been allied to the *Marsupialia;* for in the kangaroo the first toe of the fore foot is in a similar manner set obliquely to the others, like a thumb, and the disproportion between the fore and hind feet is also very great. But M. Link conceived that some of the four species of animals of which the tracks had been found in Saxony might have been gigantic *Batrachians;* and Dr. Buckland designated some of the footsteps as those of a small web-footed animal, probably crocodilian.

In the course of these discussions several naturalists of Liverpool, in their report on the Storton quarries, declared their opinion that each of the thin seams of clay in which the sandstone casts were moulded had formed successively a surface above water, over which the *Cheirotherium* and other animals walked, leaving impressions of their footsteps, and that each layer had been afterwards submerged by a sinking down of the surface, so that a new beach was formed at low water above the former, on which other tracks were then made. The repeated occurrence of ripple-marks at various heights and depths in the red sandstone of Cheshire had been explained in the same manner. It was also remarked that impressions of such depth and clearness could only have been made by animals walking on the land, as their weight would have been insufficient to make them sink so deeply in yielding clay under water. They must therefore have been air-breathers.

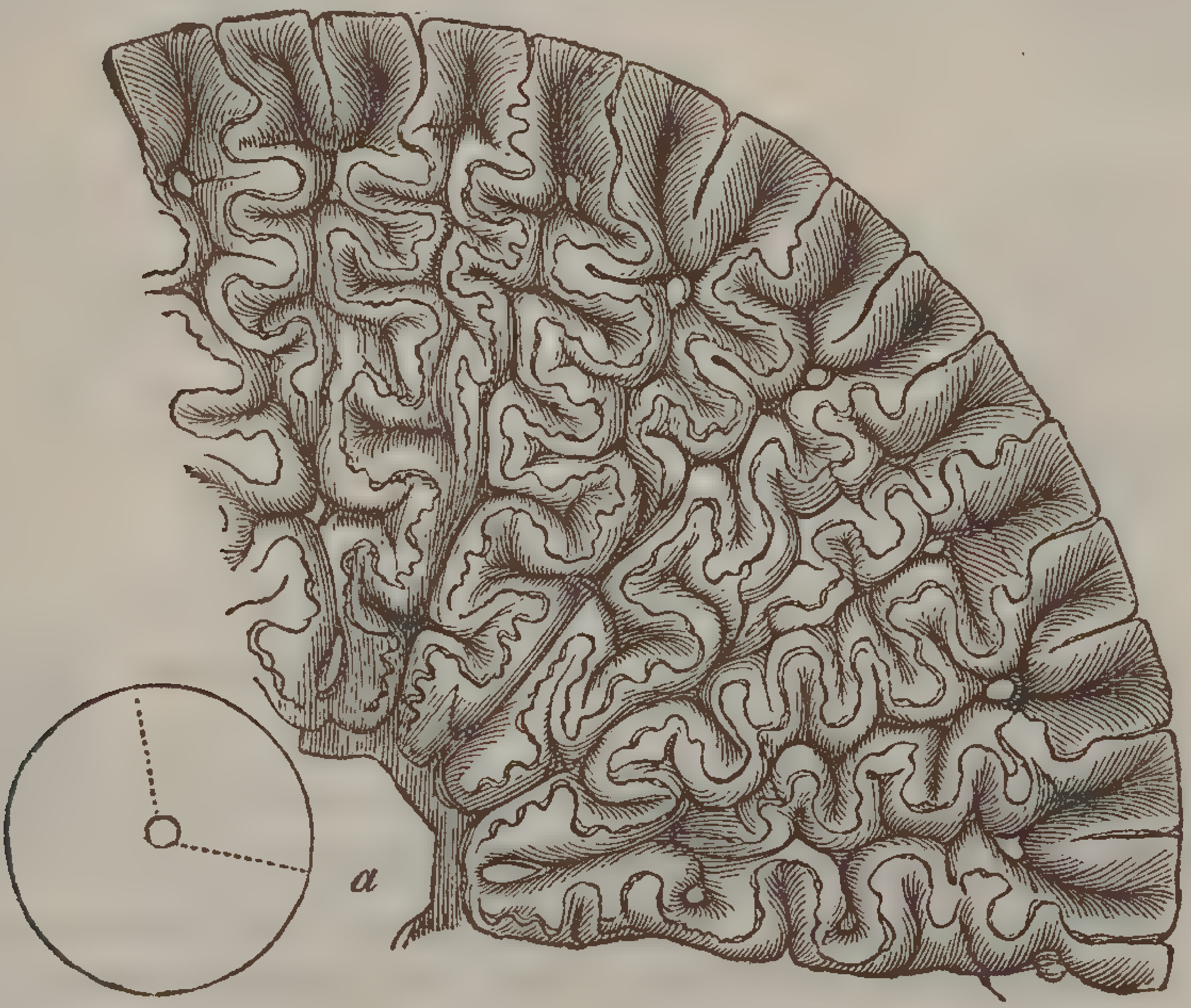
When the inquiry had been brought to this point, the reptilian remains discovered in the Trias, both of Germany and England, were carefully examined by Prof. Owen. He found, after a microscopic investigation of the teeth from the German sandstone called Keuper, and from the sandstone of Warwick and Leamington (fig. 437.), that neither of them could be referred to true saurians, although they had been named *Mastodonsaurus* and *Phytosaurus* by Jäger. It appeared that they were of the *Batrachian* order, and attested the former existence of frogs of gigantic dimensions in comparison with any now living. Both the Continental and English fossil teeth exhibited a most complicated texture, differing from that previously observed in any reptile, whether recent or extinct, but most nearly analogous to the *Ichthyosaurus.* A section of one of these teeth exhibits a series of irregular folds, resembling the labyrinthic windings of the surface of the brain; and

Fig. 437.

Tooth of *Labyrinthodon;* nat. size. Warwick sandstone.

from this character Prof. Owen has proposed the name *Labyrinthodon* for the new genus. The annexed representation (fig. 438.) of part of one is given from his "Odontography," plate 64 A. The entire length of this tooth is supposed to have been about three inches and a half, and the breadth at the base one inch and a half.

Fig. 438.



Transverse section of tooth of *Labyrinthodon Jaegeri*, Owen (*Mastodonsaurus Jaegeri*, Meyer); nat. size, and a segment magnified.

a. Pulp cavity, from which the processes of pulp and dentine radiate.

When Prof. Owen had satisfied himself, from an inspection of the cranium, jaws, and teeth, that a gigantic *Batrachian* had existed at the period of the Trias or Upper New Red Sandstone, he soon found, from the examination of various bones derived from the same formation, that he could define three species of *Labyrinthodon*, and that in this genus the hind extremities were much larger than the anterior ones. This circumstance, coupled with the fact of the *Labyrinthodon* having existed at the period when the *Cheirotherian* footsteps were made, was the first step towards the identification of those tracks with the newly discovered Batrachian. It was at the same time observed that the footmarks of *Cheirotherium* were more like those of toads than of any other living animal; and, lastly, that the size of the three species of *Labyrinthodon* corresponded with the size of three different kinds of footprints which had already been supposed to belong to three distinct *Cheirotheria*. It was moreover inferred, with confidence, that the *Labyrinthodon* was an *air-breathing* reptile from the structure of the nasal cavity, in which the posterior outlets were at the back part of the mouth, instead of being directly under the anterior or external nostrils. It must have respired air after the manner of saurians, and may therefore have imprinted on the shore those footsteps, which, as we have seen, could not have originated from an animal walking under water.

It is true that the structure of the foot is still wanting, and that a more connected and complete skeleton is required for demonstration; but the circumstantial evidence above stated is strong enough to produce the conviction that the *Cheirotherium* and *Labyrinthodon* are one and the same.

In order to show the manner in which one of these formidable Batrachians may have impressed the mark of its feet upon the shore, Prof. Owen has attempted a restoration, of which a reduced copy is annexed.

Fig. 439.

Restored outline of *Labyrinthodon pachygnathus*, Owen.

The only bones of this species at present known are those of the head, the pelvis, and part of the scapula, which are shown by stronger lines in the above figure. There is reason for believing that the head was not smooth externally, but protected by bony scutella. This character and the presence of strong conical teeth implanted in sockets, together with the elongated form of the head, induce many able anatomists, such as Von Meyer and Mantell, to regard the Labyrinthodons as more allied to crocodiles than to frogs. But the double occipital condyles, the position of some of the teeth on the vomer and palatine bones, and other characters, are considered by Messrs. Jäger and Owen to give them superior claims to be classed as batrachians. That they occupy an intermediate place is clear, but too little is yet known of the entire skeleton to enable us to determine the exact amount of their affinity to one or other of the above-named great divisions of reptiles.

Triassic Mammifer (*Microlestes antiquus*, Plieninger).—In the year 1847, Professor Plieninger, of Stuttgart, published a description of two fossil molar teeth, referred by him to a warm-blooded quadruped*, which he obtained from a bone-breccia in Würtemberg occurring between the lias and the keuper. As the announcement of so novel a fact has never met with the attention it deserved, we are indebted to Dr. Jäger, of Stuttgart, for having recently reminded us of it in his Memoir on the Fossil Mammalia of Würtemberg.†

Fig. 440. represents the tooth first found, taken from the plate published in 1847, by Professor Plieninger; and fig. 441. is a drawing of the same executed from the original by Mr. Hermann von Meyer,

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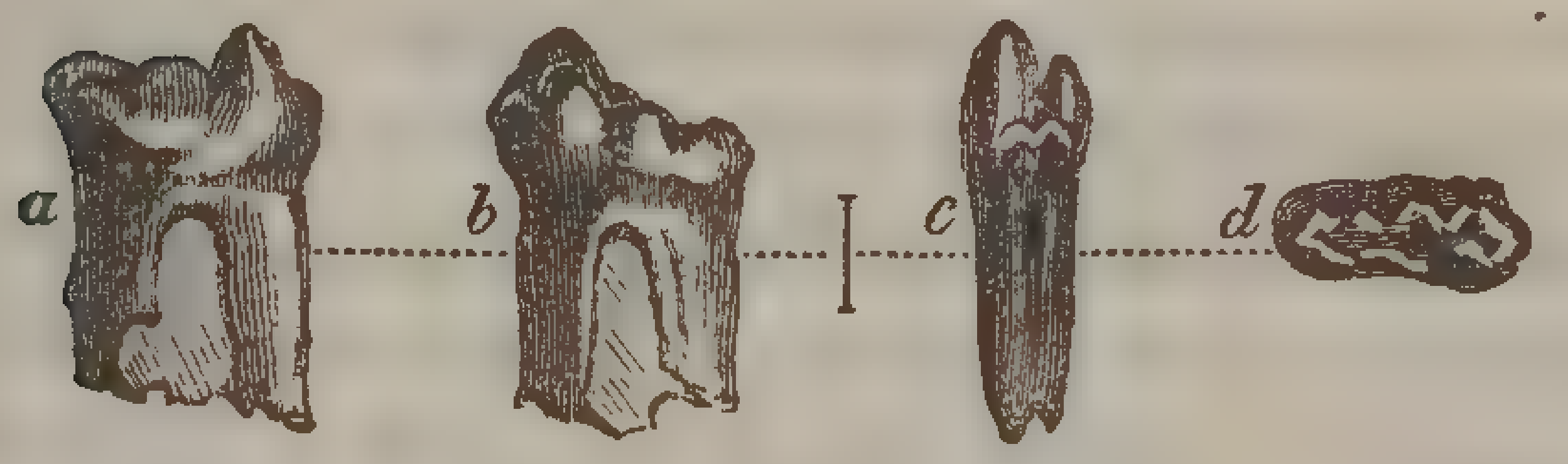
* Würtembergisch. Naturwissen Jahreshefte, 3 Jahr. Stuttgart, 1847.

† Nov. Act. Acad. Cæsar. Leopold. Nat. Cur. 1850, p. 902. For figures, see ibid. plate xxi. figs. 14, 15, 16, 17.

which he has been kind enough to send me. Fig. 442. is a second and larger molar, copied from Dr. Jäger's plate lxxi., fig. 15.

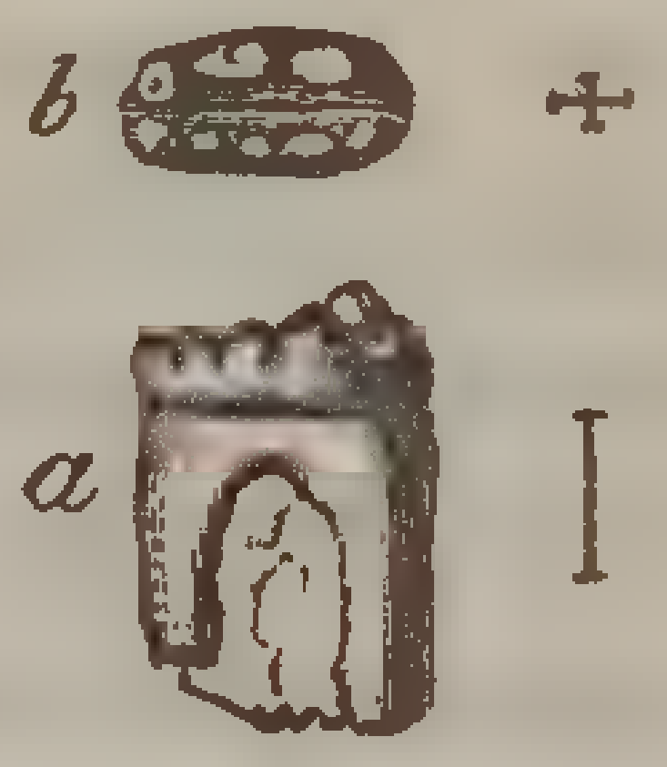
Fig. 440.



Microlestes antiquus, Plieninger. Molar tooth magnified. Upper Trias, Diegerloch, near Stuttgart, Würtemberg.

a. View of inner side? *b*. Same, outer side?
c. Same in profile. *d*. Crown of same.

Fig. 441.



Microlestes antiquus, Plien.
View of same molar as No. 440. From a drawing by Herman von Meyer.
a. View of inner side?
b. Crown of same.

Fig. 442.

Molar of *Microlestes*? Plien. 4 times as large as the fig. 440. From the trias of Diegerloch, Stuttgart.

Professor Plieninger inferred in 1847, from the double fangs of this tooth and their unequal size, and from the form and number of the protuberances or cusps on the flat crowns, that it was the molar of a Mammifer; and considering it as predaceous, probably insectivorous, he calls it *Microlestes*, from μικρος, little, and ληστης, a beast of prey. Soon afterwards, he found the second tooth, also at the same locality, Diegerloch, about two miles to the south-east of Stuttgart. Some of its cusps are broken, but there seem to have been six of them originally. From its agreement in general characters, it is supposed by Professor Plieninger to be referable to the same animal, but as it is four times as big, it may perhaps have belonged to another allied species. This molar is attached to the matrix consisting of sandstone, whereas the tooth, fig. 440., is isolated. Several fragments of bone, differing in structure from that of the associated saurians and fish, and believed to be mammalian, were imbedded near them in the same rock.

Mr. Waterhouse, of the British Museum, after studying the annexed figs. 440, 441, 442., and the descriptions of Prof. Plieninger, observes, that not only the double roots of the teeth, and their crowns presenting several cusps, resemble those of Mammalia, but the cingulum also, or ridge surrounding the base of that part of the body of the tooth which was exposed or above the gum, is a character distinguishing them from fish and reptiles. "The arrangement of the six cusps or tubercles in two rows, in fig. 440., with a groove or depression between them, and the oblong form of the tooth, lead him, he says, to regard it as a molar of the lower jaw. Both the teeth differ from those of the Stonesfield Mammalia, but do not supply sufficient data for determining to what order they belonged.

Professor Plieninger has sent me a cast of the smaller tooth, which exhibits well the characteristic mammalian test, the double fang; but Prof. Owen, to whom I have shown it, is not able to recognise its affinity with any mammalian type, recent or extinct, known to him.

It has already been stated that the stratum in which the above-mentioned fossils occur is intermediate between the lias and the uppermost member of the trias. That it is really triassic may be deduced from the following considerations. In Würtemberg there are two "bone-beds," one of great extent, and very rich in the remains of fish and reptiles, which intervenes between the muschelkalk and keuper, the other, containing the *Microlestes*, less extensive and fossiliferous, which rests on the keuper, or superior member of the trias, and is covered by the sandstone of the lias. The last-mentioned breccia, therefore, occupies nearly the same place as the well-known English "bone-bed" of Axmouth and Aust-cliff near Bristol, which is shown above, p. 338., to include characteristic species of muschelkalk fish, of the genus *Saurichthys*, *Hybodus*, and *Gyrolepis*. In both the Würtemberg bone-beds these three genera are also found, and one of the *species*, *Saurichthys Mougeotii*, is common to both the lower and upper breccias, as is also a remarkable reptile called *Nothosaurus mirabilis*. The saurian called *Belodon* by H. Von Meyer, of the Thecodont family, is another Triassic form, associated at Diegerloch with *Microlestes*.

Previous to this discovery of Professor Plieninger, the most ancient of known fossil Mammalia were those of the Stonesfield slate, above described, p. 312., no representative of this class having as yet been met with in the Fuller's earth, or inferior Oolite, nor in any member of the Lias.

Origin of Red Sandstone and Rock Salt.

We have seen that, in various parts of the world, red and mottled clays and sandstones, of several distinct geological epochs, are found associated with salt, gypsum, magnesian limestone, or with one or all of these substances. There is, therefore, in all likelihood, a general cause for such a coincidence. Nevertheless, we must not forget that there are dense masses of red and variegated sandstones and clays, thousands of feet in thickness, and of vast horizontal extent, wholly devoid of saliferous or gypseous matter. There are also deposits of gypsum and of muriate of soda, as in the blue clay formation of Sicily, without any accompanying red sandstone or red clay.

To account for deposits of red mud and red sand, we have simply to suppose the disintegration of ordinary crystalline or metamorphic schists. Thus, in the eastern Grampians of Scotland, in the north of Forfarshire, for example, the mountains of gneiss, mica-schist, and clay-slate are overspread with alluvium, derived from the disintegration of those rocks; and the mass of detritus is stained by oxide of iron, of precisely the same colour as the Old Red Sandstone of the adjoining Lowlands. Now this alluvium merely requires to be swept down to the sea, or into a lake, to form strata of red sandstone and red marl, precisely like the mass of the "Old Red" or "New Red" systems of England, or those tertiary deposits of Auvergne (see p. 199.), before described, which are in lithological characters quite undistinguishable. The pebbles of gneiss in the Eocene red sandstone of Auvergne point clearly to the rocks from which it has been derived. The red colouring matter may, as in the Grampians, have been furnished by the decomposition of hornblende or mica, which contain oxide of iron in large quantity.

It is a general fact, and one not yet accounted for, that scarcely any fossil remains are preserved in stratified rocks in which this oxide of iron abounds; and when we find fossils in the New or Old Red Sandstone in England, it is in the gray, and usually calcareous beds, that they occur.

The gypsum and saline matter, occasionally interstratified with such red clays and sandstones of various ages, primary, secondary, and tertiary, have been thought by some geologists to be of volcanic origin. Submarine and subaerial exhalations often occur in regions of earthquakes and volcanos far from points of actual eruption, and charged with sulphur, sulphuric salts, and with common salt or muriate of soda. In a word, such "solfataras" are vents by which all the products which issue in a state of sublimation from the craters of active volcanos obtain a passage from the interior of the earth to the surface. That such gaseous emanations and mineral springs, impregnated with the ingredients before enumerated, and often intensely heated, continue to flow out unaltered in composition and temperature for ages, is well known. But before we can decide on their real instrumentality in producing in the course of ages beds of gypsum, salt, and dolomite, we require to know more respecting the chemical changes actually in progress in seas where volcanic agency is at work.

The origin of rock-salt, however, is a problem of so much interest in theoretical geology as to demand the discussion of another hypothesis advanced on the subject; namely, that which attributes the precipitation of the salt to evaporation, whether of inland lakes or of lagoons communicating with the ocean.

At Northwich, in Cheshire, two beds of salt, in great part unmixed with earthy matter, attain the extraordinary thickness of 90 and even 100 feet. The upper surface of the highest bed is very uneven, forming cones and irregular figures. Between the two masses there intervenes a bed of indurated clay, traversed with veins of salt. The highest bed thins off towards the south-west, losing 15 feet in thickness in the course of a mile.* The horizontal extent of these particular masses in Cheshire and Lancashire is not exactly known; but the area, containing saliferous clays and sandstones, is supposed to exceed 150 miles in diameter, while the total thickness of the trias in the same region is estimated by Mr. Ormerod at more than 1700 feet. Ripple-marked sandstones, and the footprints of animals, before described, are observed at so many levels that we may safely assume the whole area to have undergone a slow and gradual depression during the formation of the Red Sandstone. The evidence

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* Ormerod, Quart. Geol. Journ. 1848, vol. iv. p. 277.

of such a movement, wholly independent of the presence of salt itself is very important in reference to the theory under consideration.

In the "Principles of Geology" (chap. 27.), I published a map, furnished to me by the late Sir Alexander Burnes, of that singular flat region called the Runn of Cutch, near the delta of the Indus, which is 7000 square miles in area, or equal in extent to about one-fourth of Ireland. It is neither land nor sea, but is dry during a part of every year, and again covered by salt water during the monsoons. Some parts of it are liable, after long intervals, to be overflowed by river-water. Its surface supports no grass, but is encrusted over, here and there, by a layer of salt, about an inch in depth, caused by the evaporation of sea-water. Certain tracts have been converted into dry land by upheaval during earthquakes since the commencement of the present century, and, in other directions, the boundaries of the Runn have been enlarged by subsidence. That successive layers of salt might be thrown down, one upon the other, over thousands of square miles, in such a region, is undeniable. The supply of brine from the ocean would be as inexhaustible as the supply of heat from the sun to cause evaporation. The only assumption required to enable us to explain a great thickness of salt in such an area is, the continuance, for an indefinite period, of a subsiding movement, the country preserving all the time a general approach to horizontality. Pure salt could only be formed in the central parts of basins, where no sand could be drifted by the wind, or sediment be brought by currents. Should the sinking of the ground be accelerated, so as to let in the sea freely, and deepen the water, a temporary suspension of the precipitation of salt would be the only result. On the other hand, if the area should dry up, ripple-marked sands and the footprints of animals might be formed, where salt had previously accumulated. According to this view the thickness of the salt, as well as of the accompanying beds of mud and sand, becomes a mere question of time, or requires simply a repetition of similar operations.

Mr. Hugh Miller, in an able discussion of this question, refers to Dr. Frederick Parrot's account, in his journey to Ararat (1836), of the salt lakes of Asia. In several of these lakes west of the river Manech, "the water, during the hottest season of the year, is covered on its surface with a crust of salt nearly an inch thick, which is collected with shovels into boats. The crystallization of the salt is effected by rapid evaporation from the sun's heat and the supersaturation of the water with muriate of soda; the lake being so shallow that the little boats trail on the bottom and leave a furrow behind them, so that the lake must be regarded as a wide pan of enormous superficial extent, in which the brine can easily reach the degree of concentration required."

Another traveller, Major Harris, in his "Highlands of Ethiopia," describes a salt lake, called the Bahr Assal, near the Abyssinian frontier, which once formed the prolongation of the Gulf of Tadjara, but was afterwards cut off from the gulf by a broad bar of lava or of land upraised by an earthquake. "Fed by no rivers, and exposed in a burning climate to the unmitigated rays of the sun, it has shrunk into an elliptical basin, seven miles in its transverse axis, half filled with smooth water of the deepest cœrulian hue, and half with a solid sheet of glittering snow-white salt, the offspring of evaporation." "If," says Mr. Hugh Miller, "we suppose, instead of a barrier of lava, that sand-bars were raised by the surf on a flat arenaceous coast during a slow and equable sinking of the surface, the waters of the outer gulf might occasionally topple over the bar, and supply fresh brine when the first stock had been exhausted by evaporation."*

We may add that the permanent impregnation of the waters of a large shallow basin with salt, beyond the proportion which is usual in the ocean, would cause it to be uninhabitable by molluscs or fish, as is the case in the Dead Sea, and the muriate of soda might remain in excess, even though it were occasionally replenished by irruptions of the sea. Should the saline deposit be eventually submerged, it might, as we have seen from the example of the Runn of Cutch, be covered by a freshwater formation containing fluviatile organic remains; and in this way the apparent anomaly of beds of sea-salt and clays devoid of marine fossils, alternating with others of freshwater origin, may be explained.

Dr. G. Buist, in a recent communication to the Bombay Geographical Society (vol. ix.), has asked how it happens that the Red Sea should not exceed the open ocean in saltness, by more than $\frac{1}{10}$th per cent. The Red Sea receives no supply of water from any quarter save through the Straits of Babelmandeb; and there is not a single river or rivulet flowing into it from a circuit of 4000 miles of shore. The countries around are all excessively sterile and arid, and composed, for the most part, of burning deserts. From the ascertained evaporation in the sea itself, Dr. Buist computes that nearly 8 feet of pure water must be carried off from the whole of its surface annually, this being probably equivalent to $\frac{1}{100}$th part of its whole volume. The Red Sea, therefore, ought to have 1 per cent. added annually to its saline contents; and as these constitute 4 per cent. by weight, or $2\frac{1}{2}$ per cent. in volume of its entire mass, it ought, assuming the average depth to be 800 feet, which is supposed to be far beyond the truth, to have been converted into one solid salt formation in less than 3000 years.† Does the Red Sea receive a supply of water from the ocean, through the narrow Straits of Babelmandeb, sufficient to balance the loss by evaporation? And is there an undercurrent of heavier saline water annually flowing outwards? If not, in what manner is the excess of salt disposed of? An investigation of this subject by our nautical surveyors may perhaps aid the geologist in framing a true theory of the origin of rock-salt.

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* Hugh Miller, First Impressions of England, 1847, pp. 183. 214.

† Buist, Trans. of Bombay Geograph. Soc. 1850, vol. ix. p. 38.

On the New Red Sandstone of the Valley of the Connecticut River in the United States.

In a depression of the granitic or hypogene rocks in the States of Massachusetts and Connecticut, strata of red sandstone, shale, and conglomerate are found occupying an area more than 150 miles in length from north to south, and about 5 to 10 miles in breadth, the beds dipping to the eastward at angles varying from 5 to 50 degrees. The extreme inclination of 50 degrees is rare, and only observed in the neighbourhood of masses of trap which have been intruded into the red sandstone while it was forming, or before the newer parts of the deposit had been completed. Having examined this series of rocks in many places, I feel satisfied that they were formed in shallow water, and for the most part near the shore, and that some of the beds were from time to time raised above the level of the water, and laid dry, while a newer series, composed of similar sediment, was forming. The red flags of thin-bedded sandstone are often ripple-marked, and exhibit on their under-sides casts of cracks formed in the underlying red and green shales. These last must have shrunk by drying before the sand was spread over them. On some shales of the finest texture impressions of rain-drops may be seen, and casts of them in the incumbent argillaceous sandstones. Having observed similar markings produced by showers, of which the precise date was known, on the recent red mud of the Bay of Fundy, and casts in relief of the same on layers of dried mud thrown down by subsequent tides*, I feel no doubt in regard to the origin of some of the ancient Connecticut impressions. I have also seen on the mud-flats of the Bay of Fundy the footmarks of birds (*Tringa minuta*), which daily run along the borders of that estuary at low water, and which I have described in my Travels.† Similar layers of red mud, now hardened and compressed into shale, are laid open on the banks of the Connecticut, and retain faithfully the impressions and casts of the feet of numerous birds and reptiles which walked over them at the time when they were deposited, probably in the Triassic Period.

According to Professor Hitchcock, the footprints of no less than thirty-two species of bipeds, and twelve of quadrupeds, have been already detected in these rocks. Thirty of these are believed to be those of birds, four of lizards, two of chelonians, and six of batrachians. The tracks have been found in more than twenty places, scattered through an extent of nearly 80 miles from north to south, and they are repeated through a succession of beds attaining at some points a thickness of more than 1000 feet, which may have been thousands of years in forming.‡

As considerable scepticism is naturally entertained in regard to

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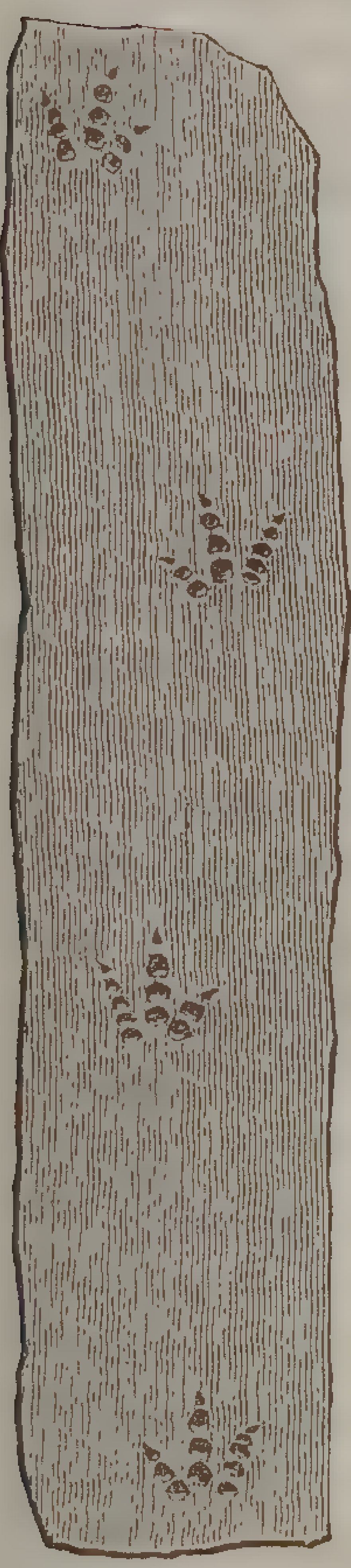
* Principles of Geology, 9th ed. p. 203.

† Travels in North America, vol. ii. p. 168.

‡ Hitchcock, Mem. of Amer. Acad. New Ser. vol. iii. p. 129.

the nature of the evidence derived from footprints, it may be well to enumerate some facts respecting them on which the faith of the geologist may rest. When I visited the United States in 1842, more than 2000 impressions had been observed by Professor Hitchcock*, in the district alluded to, and all of them were indented on the upper surface of the layers, while the corresponding casts, standing out in relief, were always on the lower surfaces or planes of the strata. If we follow a single line of marks we find them uniform in size, and nearly uniform in distance from each other, the toes of two successive footprints turning alternately right and left (see fig. 443.). Such single lines indicate a biped; and there is generally such a deviation from a straight line, in any three successive prints, as we remark in the tracks left by birds. There is also a striking relation between the distance separating two footprints in one series and the size of the impressions; in other words, an obvious proportion between the length of the stride and the dimension of the creature which walked over the mud. If the marks are small, they may be half an inch asunder; if gigantic, as, for example, where the toes are 20 inches long, they are occasionally 4 feet and a half apart. The bipedal impressions are for the most part trifid, and show the same number of joints as exist in the feet of living tridactylous birds. Now, such birds have three phalangeal bones for the inner toe, four for the middle, and five for the outer one (see fig. 443.); but the impression of the terminal joint is that of the nail only. The fossil footprints exhibit regularly, where the joints are seen, the same number; and we see in each continuous line of tracks the three-jointed and five-jointed toes placed alternately outwards, first on the one side and then on the other. In some specimens, besides impressions of the three toes in front, the rudiment is seen of the fourth toe behind. It is not often that the matrix has been fine enough to retain impressions of the integument or skin of the foot; but in one fine specimen found at Turner's Falls on the Connecticut, by Dr. Deane, these markings are well preserved, and have been recognized by Prof. Owen as resembling the skin of the ostrich, and not that of reptiles.† Much care is required to ascertain the precise layer of a laminated rock on which an animal has walked, because the impression usually extends downwards through several laminæ; and if the upper layer originally

Fig. 443.



Footprints of a bird. Turner's Falls, Valley of the Connecticut. (See Dr. Deane, Mem. of Amer. Acad. vol. iv. 1849.)

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* See also Mem. Amer. Ac. vol. iii. 1848.

† This specimen was in the late Dr. Mantell's museum, and indicated a bird of a size intermediate between the small and the largest of the Connecticut species.

trodden upon is wanting, the mark of one or more joints, or even in some cases an entire toe, which sank less deep into the soft ground, may disappear. and yet the remainder of the footprint be well defined.

The size of several of the fossil impressions of the Connecticut red sandstone so far exceeds that of any living ostrich, that naturalists at first were extremely adverse to the opinion of their having been made by birds, until the bones and almost entire skeleton of the *Dinornis* and of other feathered giants of New Zealand were discovered. Their dimensions have at least destroyed the force of this particular objection. The magnitude of the impressions of the feet of a heavy animal, which has walked on suft mud, increases for some distance below the surface originally trodden upon. In order, therefore, to guard against exaggeration, the casts rather than the mould are relied on. These casts show that some of the fossil bipeds had feet four times as large as the ostrich, but not perhaps much larger than the *Dinornis.*

The eggs of another gigantic bird, called *Æpiornis,* which has probably been exterminated by man, have recently been discovered in an alluvial deposit in Madagascar. The egg has six times the capacity of that of the ostrich; but, judging from the large size of the egg of the *Apterix*, Prof. Owen does not believe that the *Æpiornis* exceeded, if indeed it equalled, the *Dinornis* in stature.

Among the supposed bipedal tracks, a single distinct example only has been observed of feet in which there are four toes directed forwards. In this case a series of four footprints is seen, each 22 inches long and 12 wide, with joints much resembling those in the toes of birds. Professor Agassiz has suggested that it might have belonged to a gigantic bipedal batrachian. Other naturalists have called our attention to the fact, that some quadrupeds, when walking, place the hind foot so precisely on the spot just quitted by the fore foot, as to produce a single line of imprints, like those of a biped; and Mr. Waterhouse Hawkins has remarked that certain species of frogs and lizards in Australia have the two outer toes so slightly developed and so much raised that they might leave tridactylous footprints on mud and sand. Another osteologist, Dr. Leidy, in the United States, observed to me that the pterodactyl was a bipedal reptile approaching the bird so nearly in the structure and shape of its wing-bones and tibiæ, that some of these last, obtained from the Chalk and Wealden in England, had been mistaken by the highest authorities for true birds' bones. May not the foot, therefore, of a pterodactyl have equally resembled that of a bird? Be this as it may, the greater number of the American impressions agree so precisely in form and size with the footmarks of known living birds, especially with those of waders, that we shall act most in accordance with known analogies by referring most of them at present to feathered, rather than to featherless bipeds.

No bones have as yet been met with, whether of pterodactyl or bird, in the rocks of the Connecticut, but there are numerous coprolites; and an ingenious argument has been derived by Dr. Dana from the analysis of these bodies, and the proportion they contain of uric acid, phosphate of lime, carbonate of lime, and organic matter, to show that, like guano, they are the droppings of birds, rather than of reptiles.

Some of the quadrupedal footprints which accompany those of birds are analogous to European *Cheirotheria*, and with a similar disproportion between the hind and fore feet. Others resemble that remarkable reptile, the *Rhyncosaurus* of the English Trias, a creature having some relation in its osteology both to chelonians and birds. Other imprints, again, are like those of turtles.

Mr. Darwin, in his "Journal of a Voyage in the Beagle," informs us that the "South American ostriches, although they live on vegetable matter, such as roots and grass, are repeatedly seen at Bahia Blanca (lat. 39° S.), on the coast of Buenos Ayres, coming down at low water to the extensive mud-banks which are then dry, for the sake, as the Gauchos say, of feeding on small fish." They readily take to the water, and have been seen at the bay of San Blas, and at Port Valdez, in Patagonia, swimming from island to island.* It is therefore evident, that in our times a South American mud-bank might be trodden simultaneously by ostriches, alligators, tortoises, and frogs; and the impressions left, in the nineteenth century, by the feet of these various tribes of animals, would not differ from each other more entirely than do those attributed to birds, saurians, chelonians, and batrachians in the rocks of the Connecticut.

To determine the exact age of the red sandstone and shale containing these ancient footprints in the United States, is not possible at present. No fossil shells have yet been found in the deposit, nor plants in a determinable state. The fossil fish are numerous and very perfect; but they are of a peculiar type, which was originally referred to the genus *Palæoniscus*, but has since, with propriety, been ascribed, by Sir Philip Egerton, to a new genus. To this he has given the name of *Ischypterus*, from the great size and strength of the fulcral rays of the dorsal fin (from ἰσχὺς, strength, and πτερὸν, a fin). They differ from *Palæoniscus*, as Mr. Redfield first pointed out, by having the vertebral column prolonged to a more limited extent into the upper lobe of the tail, or, in the language of M. Agassiz, they are less heterocercal. The teeth also, according to Sir P. Egerton, who, in 1844, examined for me a fine series of specimens which I procured at Durham, Connecticut, differ from those of *Palæoniscus* in being strong and conical.

That the sandstones containing these fish are of older date than the strata containing coal, before described (p. 331.) as occurring near Richmond in Virginia, is highly probable. These were shown to be as old at least as the oolite and lias. The higher antiquity of the Connecticut beds cannot be proved by direct superposition, but may be presumed from the general structure of the country. That

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* Journal of Voyage of Beagle, &c. 2d edition, p. 89. 1845.

structure proves them to be newer than the movements to which the Appalachian or Alleghany chain owes its flexures, and this chain includes the ancient coal-formation among its contorted rocks. The unconformable position of this *New Red* with ornithichnites on the edges of the inclined primary or paleozoic rocks of the Appalachians is seen at 4. of the section, fig. 505. p. 392. The absence of fish with decidedly heterocercal tails may afford an argument against the Permian age of the formation; and the opinion that the red sandstone is triassic, seems, on the whole, the best that we can embrace in the present state of our knowledge.

CHAPTER XXIII.

PERMIAN OR MAGNESIAN LIMESTONE GROUP.

Fossils of Magnesian Limestone and Lower New Red distinct from the Triassic — Term Permian — English and German equivalents — Marine shells and corals of English Magnesian limestone — Palæoniscus and other fish of the marl-slate — Thecodont Saurians of dolomitic conglomerate of Bristol — Zechstein and Rothliegendes of Thuringia — Permian Flora — Its generic affinity to the Carboniferous — Psaronites or tree-ferns.

When the use of the term "Poikilitic" was explained in the last chapter, I stated, that in some parts of England it is scarcely possible to separate the red marls and sandstones so called (originally named "the New Red") into two distinct geological systems. Nevertheless, the progress of investigation, and a careful comparison of English rocks between the lias and the coal with those occupying a similar geological position in Germany and Russia, have enabled geologists to divide the Poikilitic formation; and has even shown that the lowermost of the two divisions is more closely connected, by its fossil remains, with the carboniferous group than with the trias. If, therefore, we are to draw a line between the secondary and primary fossiliferous strata, as between the tertiary and secondary, it must run through the middle of what was once called the "New Red," or Poikilitic group. The inferior half of this group will rank as Primary or Paleozoic, while its upper member will form the base of the Secondary series. For the lower, or Magnesian Limestone division of English geologists, Sir R. Murchison proposed, in 1841, the name of Permian, from Perm, a Russian government where these strata are more extensively developed than elsewhere, occupying an area twice the size of France, and containing an abundant and varied suite of fossils.

Prof. King, in his valuable monograph* of the Permian fossils of England, has given a table of the following six members of the Permian system of the north of England, with what he conceives to be the corresponding formations in Thuringia.

North of England.	Thuringia.
1. Crystalline or concretionary, and non-crystalline limestone.	1. Stinkstein.
2. Brecciated and pseudo-brecciated limestone.	2. Rauchwacke.
3. Fossiliferous limestone.	3. Dolomite, or Upper Zechstein.
4. Compact limestone.	4. Zechstein, or Lower Zechstein.
5. Marl-slate.	5. Mergel-schiefer, or Kupferschiefer.
6. Inferior sandstones of various colours.	6. Rothliegendes.

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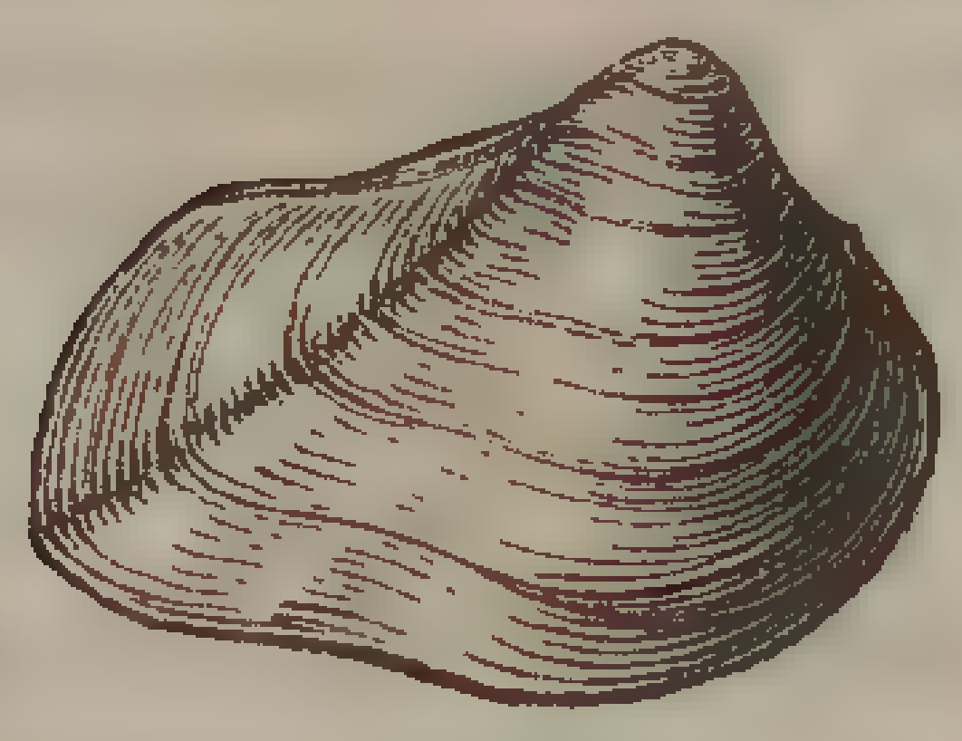
* Palæontographical Society, 1850, London.

I shall proceed, therefore, to treat briefly of these subdivisions, beginning with the highest, and referring the reader, for a fuller description of the lithological character of the whole group, as it occurs in the north of England, to a valuable memoir by Professor Sedgwick, published in 1835.*

Crystalline or concretionary limestone (No. 1.). — This formation is seen upon the coast of Durham and Yorkshire, between the Wear and the Tees. Among its characteristic fossils are *Schizodus Schlotheimi* (fig. 444.) and *Mytilus septifer* (fig. 446.).

Fig. 444.



Schizodus Schlotheimi, Geinitz.
Crystalline limestone, Permian.

Fig. 445.

The hinge of *Schizodus truncatus*, King.
Permian.

Fig. 446.

Mytilus septifer, King.
Syn. *Modiola acuminata*, James Sow.
Permian crystalline limestone.

These shells occur at Hartlepool and Sunderland, where the rock assumes an oolitic and botroidal character. Some of the beds in this division are ripple-marked; and Mr. King imagines that the absence of corals and the character of the shells indicate shallow water. In some parts of the coast of Durham, where the rock is not crystalline, it contains as much as forty-four per cent. of carbonate of magnesia, mixed with carbonate of lime. In other places, — for it is extremely variable in structure, — it consists chiefly of carbonate of lime, and has concreted into globular and hemispherical masses, varying from the size of a marble to that of a cannon-ball, and radiating from the centre. Occasionally earthy and pulverulent beds pass into compact limestone or hard granular dolomite. The stratification is very irregular, in some places well-defined, in others obliterated by the concretionary action which has re-arranged the materials of the rocks subsequently to their original deposition. Examples of this are seen at Pontefract and Ripon in Yorkshire.

The *brecciated limestone* (No. 2.) contains no fragments of foreign rocks, but seems composed of the breaking-up of the Permian limestone itself, about the time of its consolidation. Some of the angular masses in Tynemouth Cliff are 2 feet in diameter. This breccia is considered by Professor Sedgwick as one of the forms of the preceding limestone, No. 1., rather than as regularly underlying it. The fragments are angular and never water-worn, and appear to have been re-cemented on the spot where they were formed. It is, therefore, suggested that they may have been due to those internal movements of the mass which produced the concretionary structure; but the subject is very obscure, and after studying the phenomenon in the Marston Rocks, on the coast of Durham, I found it impossible

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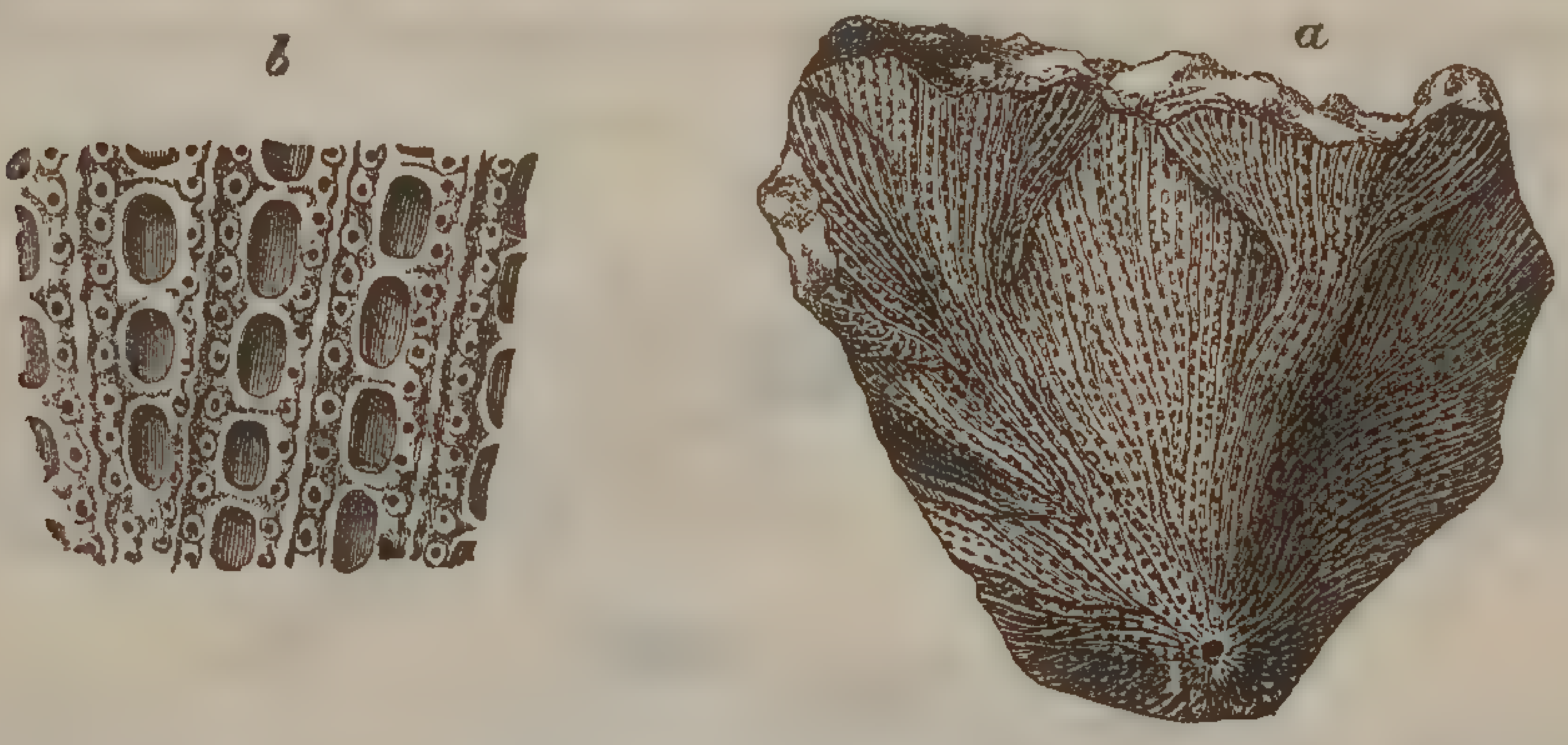
* Trans. Geol. Soc. Lond., Second Series, vol. iii. p. 37.

to form any positive opinion on the subject. The well-known brecciated limestones of the Pyrenees appeared to me to present the nearest analogy, but on a much smaller scale.

The *fossiliferous limestone* (No. 3.) is regarded by Mr. King as a deep-water formation, from the numerous delicate bryozoa which it includes. One of these, *Fenestella retiformis* (fig. 447.), is a very variable species, and has received many different names. It sometimes attains a large size, measuring 8 inches in width. The same zoophyte, or rather mollusk, with several other British species, is also found abundantly in the Permian of Germany.

Fig. 447.



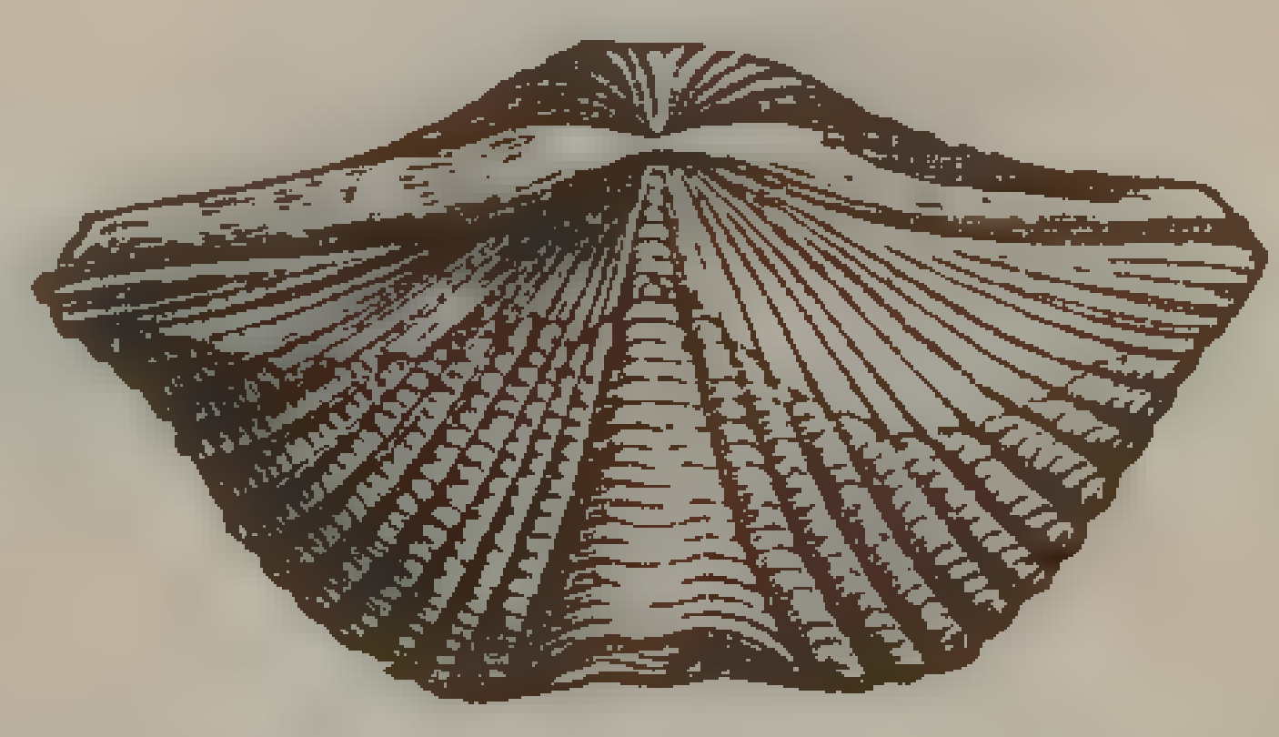
a. Fenestella retiformis, Schlot. sp.
Syn. *Gorgonia infundibuliformis*, Goldf.; *Retepora flustracea*, Phillips.
b. Part of the same highly magnified.
Magnesian limestone, Humbleton Hill, near Sunderland.*

Shells of the genera *Productus* (fig. 448.) and *Strophalosia* (the latter an allied form with teeth in the hinge), which do not occur in strata newer than the Permian, are abundant in this division of the series in the ordinary yellow magnesian limestone. They are accompanied by certain species of *Spirifer* (fig. 449.), and other brachiopoda of the true primary or paleozoic type. Some of this same tribe of shells, such as *Athyris Roissyi*, allied to *Terebratula*, are specifically the same as fossils of the carboniferous rocks. *Avicula, Arca*, and *Schizodus* (see above, figs. 444, 445, 446.), and other lamellibranchiate bivalves, are abundant, but spiral univalves are very rare.

Fig. 448.

Productus horridus, Sowerby
(including *P. calvus*, Sow.)
Sunderland and Durham, in Magnesian Limestone; Zechstein and Kupferschiefer, Germany.

Fig. 449.



Spirifer undulatus, Sow. Min. Con.
Syn. *Triogonotreta undulata*, King's Monogr.
Magnesian Limestone.

The *compact limestone* (No. 4.) also contains organic remains, especially bryozoa, and is intimately connected with the preceding.

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* King's Monograph, pl. 2.

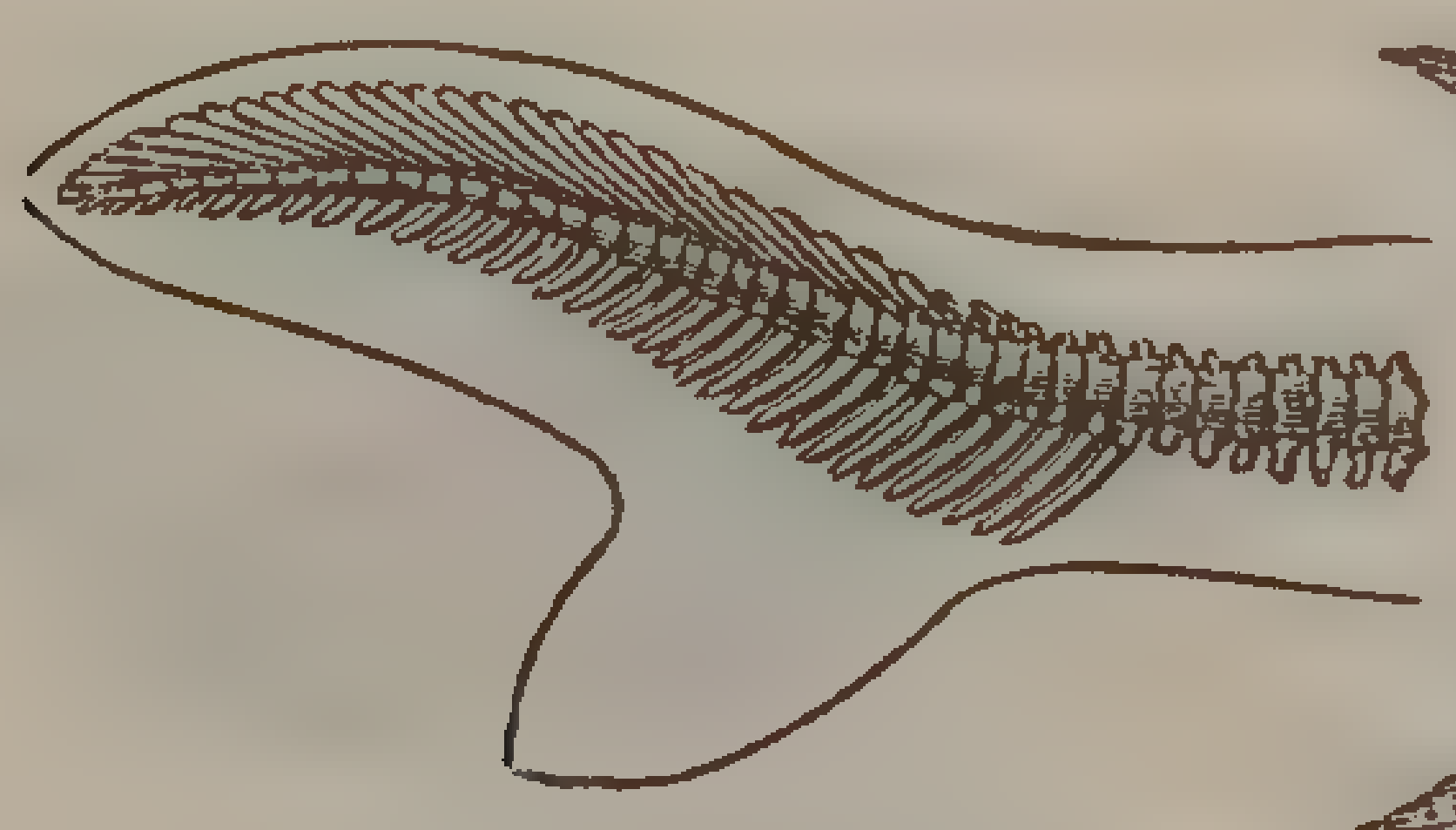
Beneath it lies the *marl-slate* (No. 5.), which consists of hard, calcareous shales, marl-slate, and thin-bedded limestones. At East Thickley, in Durham, where it is thirty feet thick, this slate has yielded many fine specimens of fossil fish of the genera *Palæoniscus*, *Pygopterus*, *Cœlacanthus*, and *Platysomus*, genera which are all found in the coal-measures of the carboniferous epoch, and which therefore, says Mr. King, probably lived at no great distance from the shore. But the Permian species are peculiar, and, for the most part, identical with those found in the marl-slate or copper-slate of Thuringia.

Fig. 450.

Restored outline of a fish of the genus *Palæoniscus*, Agass.
Palæothrissum, Blainville.

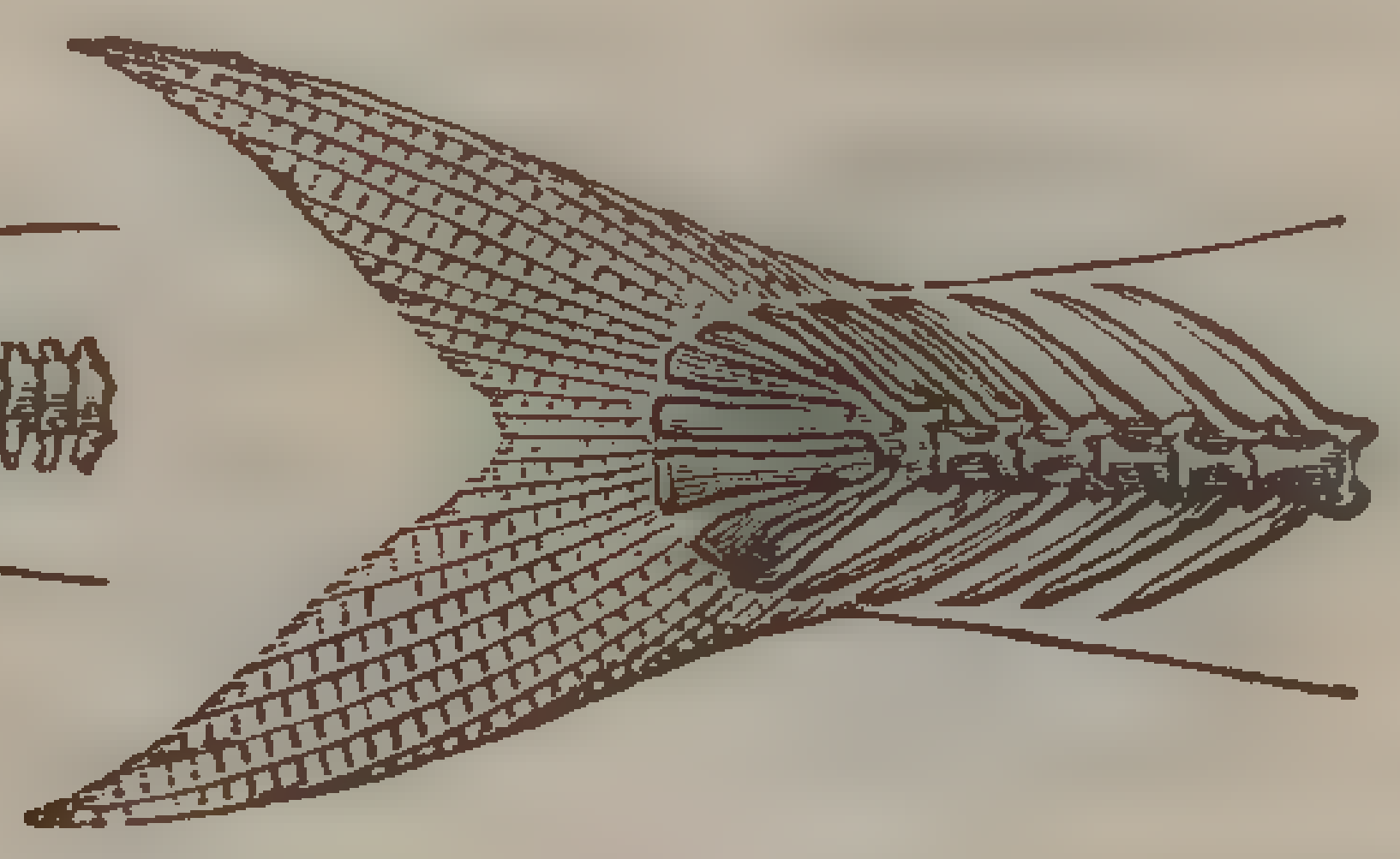
The *Palæoniscus* above mentioned belongs to that division of fishes which M. Agassiz has called "Heterocercal," which have their tails unequally bilobate, like the recent shark and sturgeon, and the vertebral column running along the upper caudal lobe. (See fig. 451.) The "Homocercal" fish, which comprise almost all the 8000 species at present known in the living creation, have the tail-fin either single or equally divided; and the vertebral column stops short, and is not prolonged into either lobe. (See fig. 452.)

Fig. 451.



Shark.
Heterocercal.

Fig. 452.



Shad. (*Clupea*, Herring tribe.)
Homocercal.

Now it is a singular fact, first pointed out by Agassiz, that the heterocercal form, which is confined to a small number of genera in the existing creation, is universal in the Magnesian limestone, and all the more ancient formations. It characterizes the earlier periods of the earth's history, when the organization of fishes made a greater approach to that of saurian reptiles than at later epochs. In all the strata above the Magnesian limestone the homocercal tail predominates.

A full description has been given by Sir Philip Egerton of the species of fish characteristic of the marl-slate, in Prof. King's monograph before referred to, where figures of the ichthyolites, which are very entire and well preserved, will be found. Even a single scale is usually so characteristically marked as to indicate the genus, and sometimes even the particular species. They are often scattered through the beds singly, and may be useful to a geologist in determining the age of the rock.

Scales of fish. Magnesian limestone.

Fig. 453.

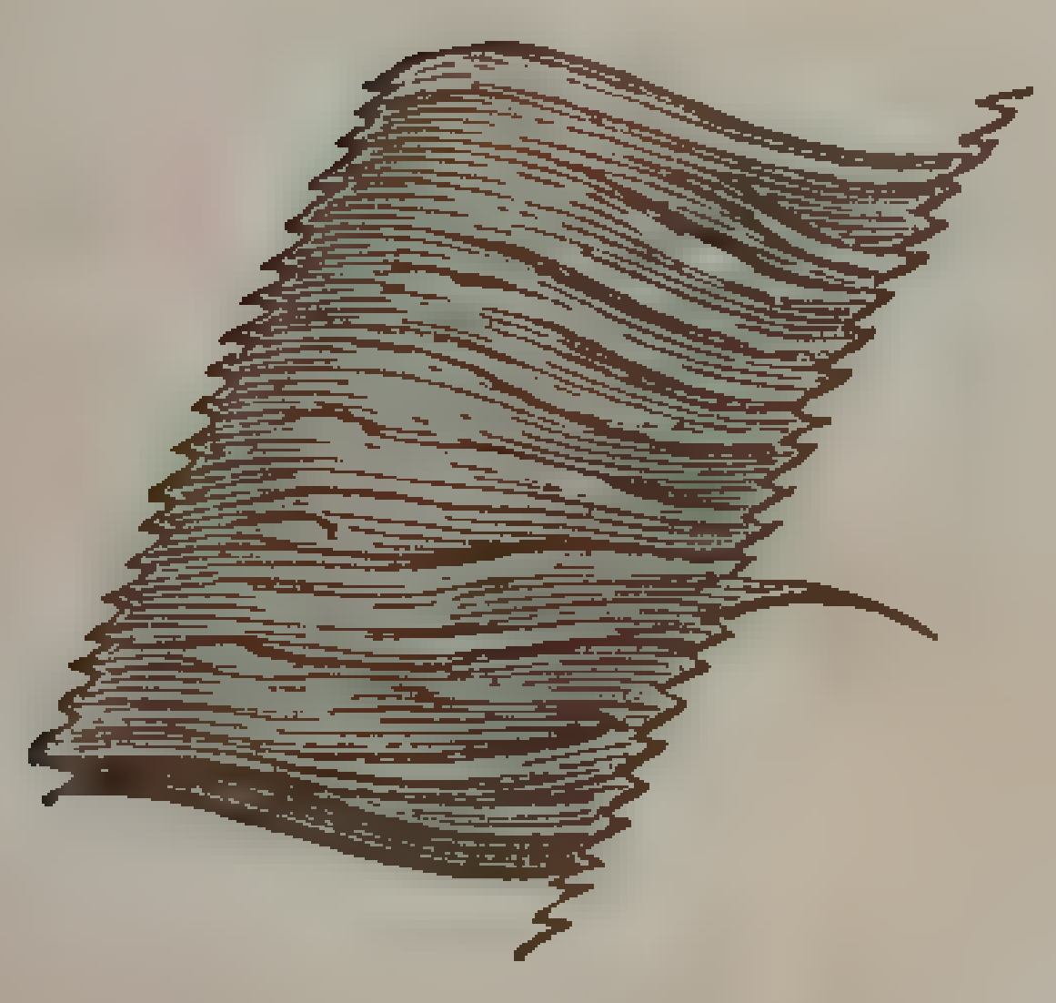


Fig. 454.

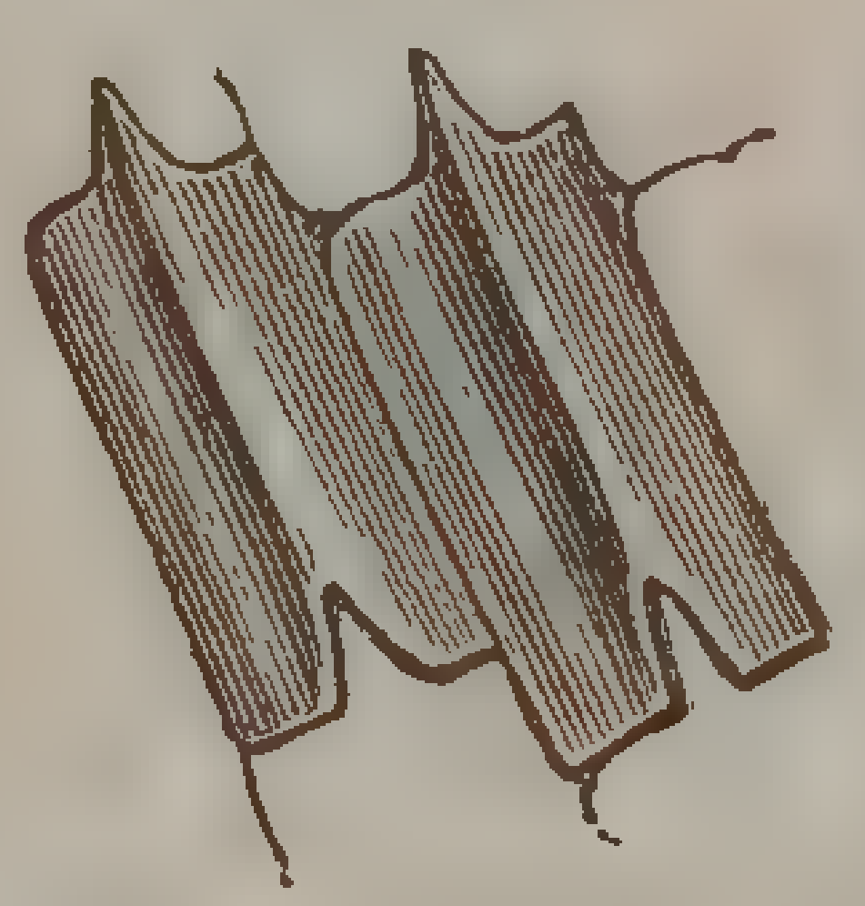


Fig. 455.

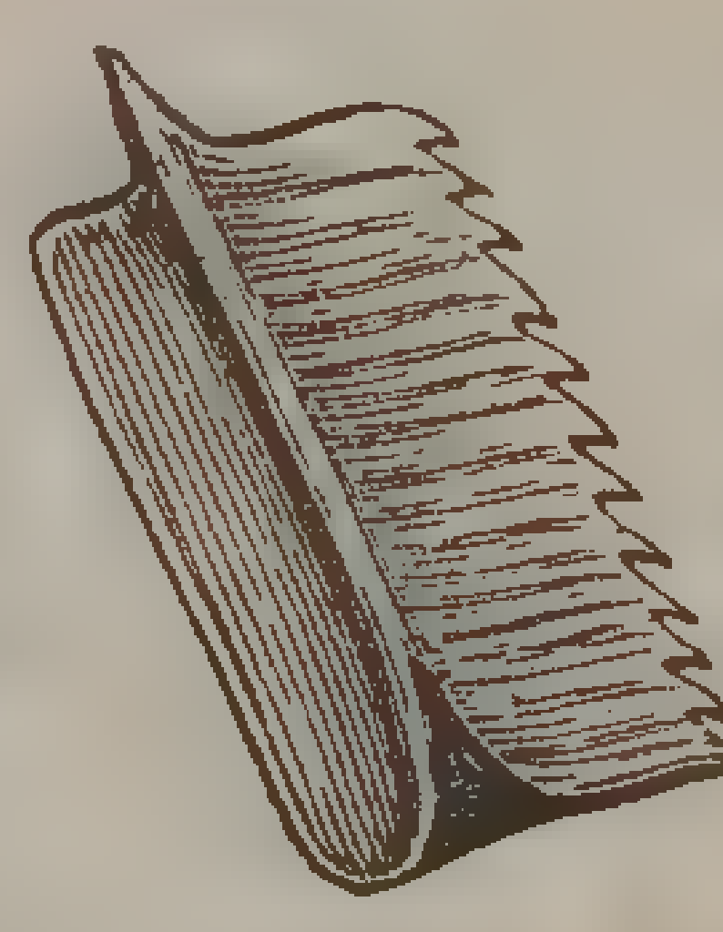


Fig. 456.

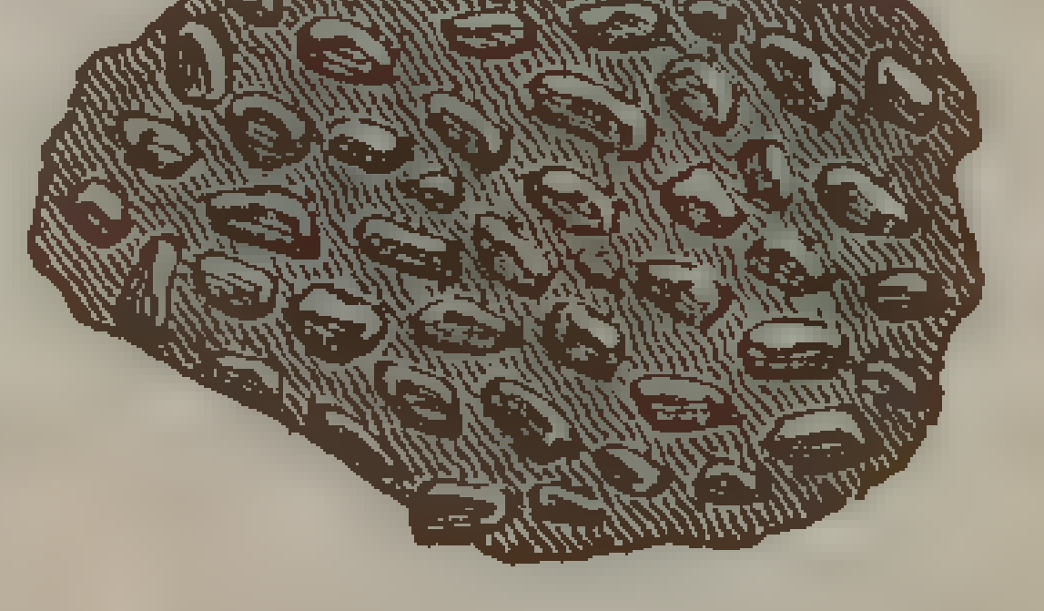
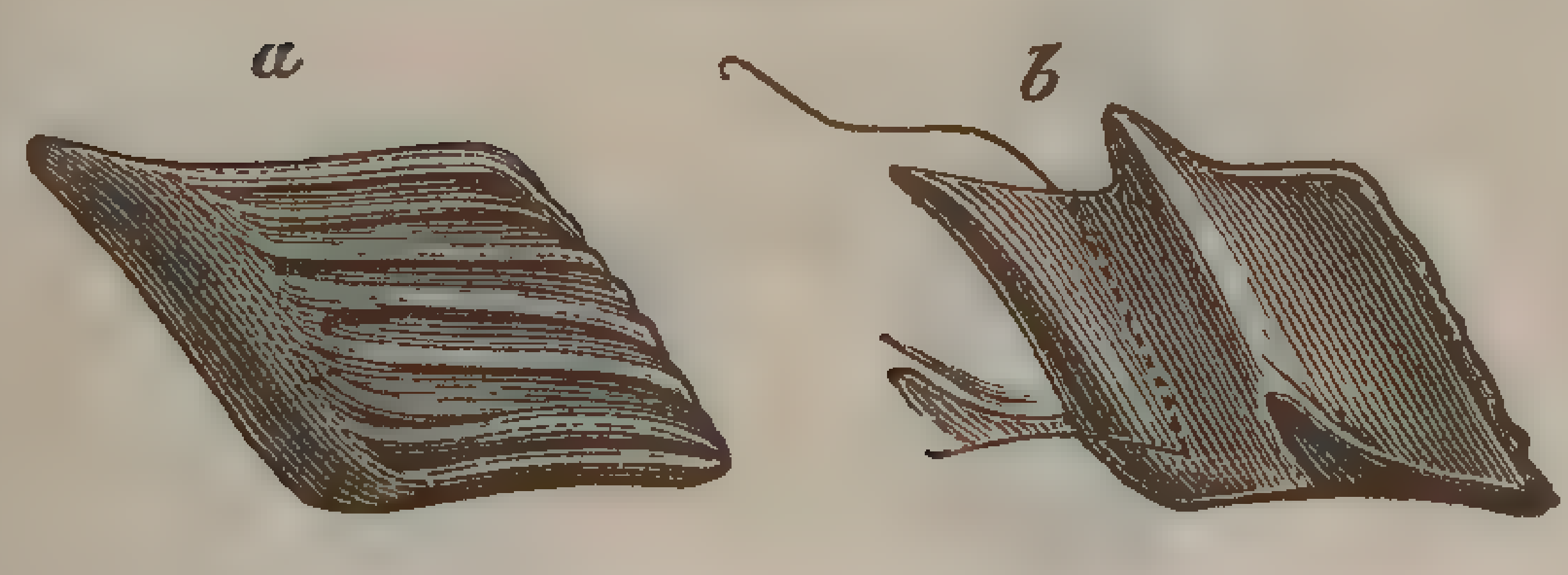


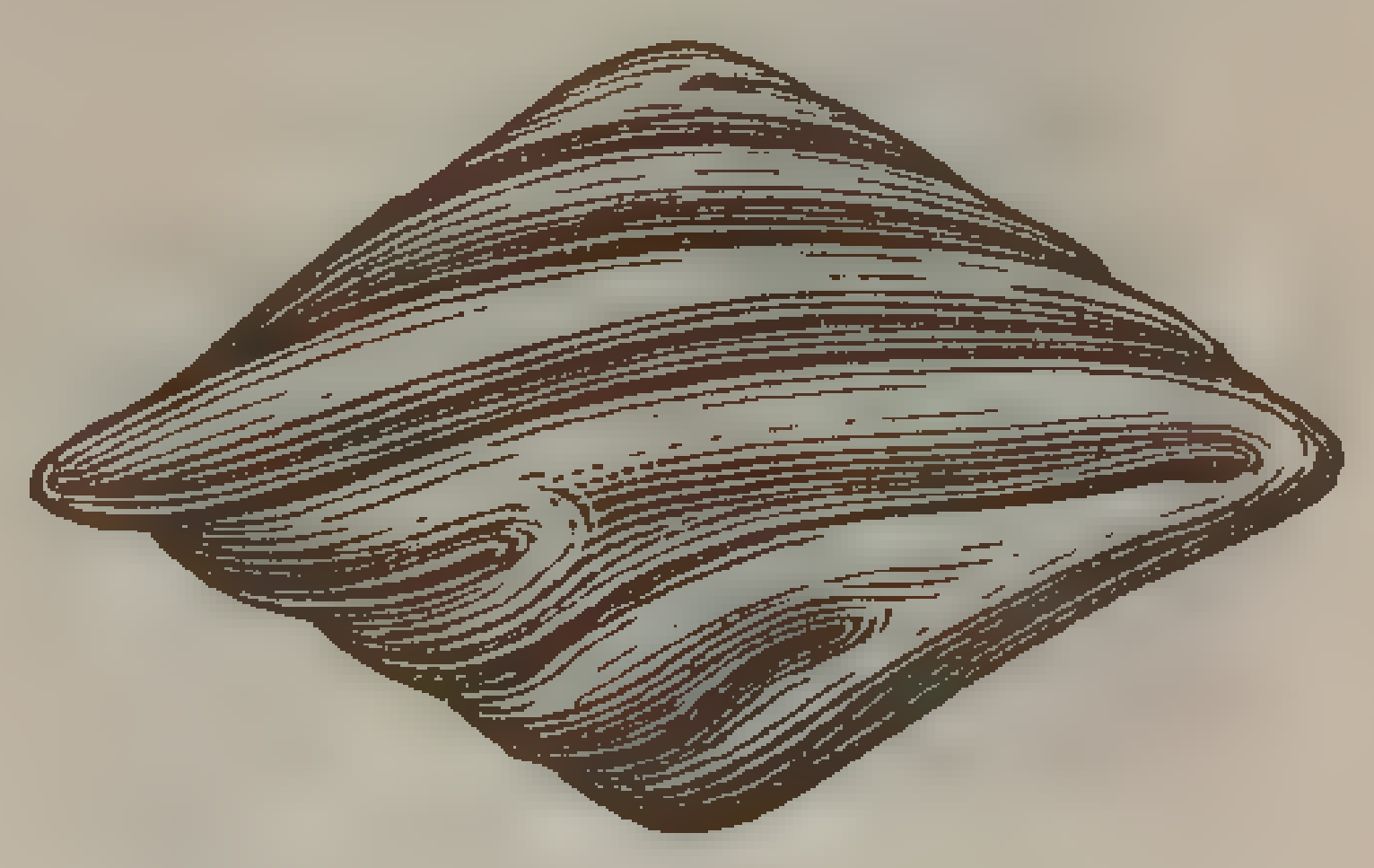
Fig. 453. *Palæoniscus comptus*, Agassiz. Scale magnified. Marl-slate.
Fig. 454. *Palæoniscus elegans*, Sedg. Under surface of scale magnified. Marl-slate.
Fig. 455. *Palæoniscus glaphyrus*, Ag. Under surface of scale magnified. Marl-slate.
Fig. 456. *Cœlacanthus granulatus*, Ag. Granulated surface of scale magnified. Marl-slate.

Fig. 457.



Pygopterus mandibularis, Ag. Marl-slate.
a. Outside of scale magnified.
b. Under surface of same.

Fig. 458.



Acrolepis Sedgwickii, Ag.
Outside of scale magnified.
Marl-slate.

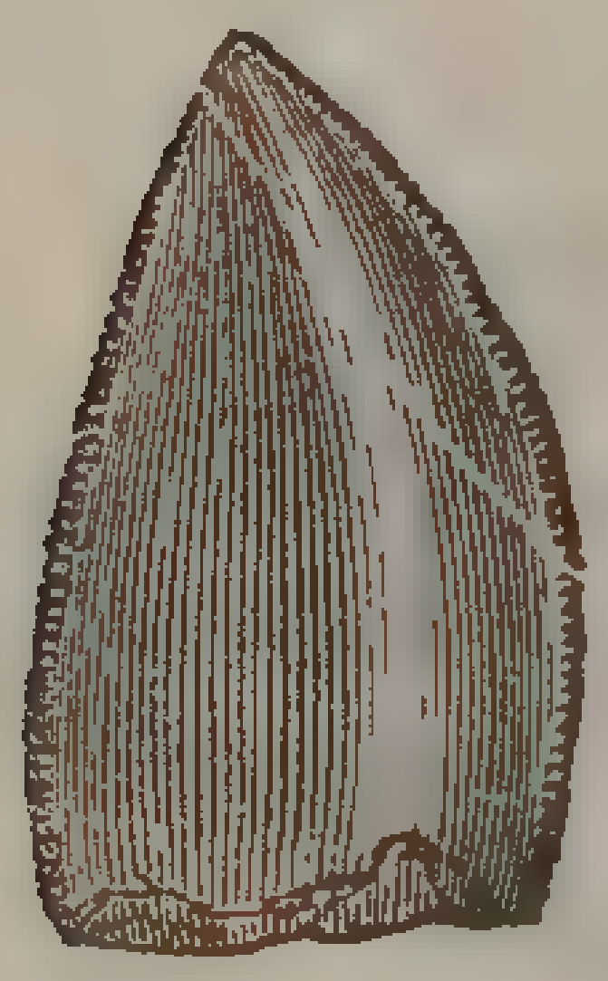
The *inferior sandstones* (No. 6. Tab. p. 353.), which lie beneath the marl-slate, consist of sandstone and sand, separating the magnesian limestone from the coal, in Yorkshire and Durham. In some instances, red marl and gypsum have been found associated with these beds. They have been classed with the magnesian limestone by Professor Sedgwick, as being nearly co-extensive with it in geographical range, though their relations are very obscure. In some regions we find it stated that the imbedded plants are all specifically identical with those of the carboniferous series; and, if so, they probably belong to that epoch; for the true Permian flora appears, from the researches of MM. Murchison and de Verneuil in Russia, and of Colonel von Gutbier in Saxony, to be, with few exceptions, distinct from that of the coal (see p. 359.).

Dolomitic conglomerate of Bristol.—Near Bristol, in Somersetshire, and in other counties bordering the Severn, the unconformable beds of the Lower New Red, resting immediately upon the Coal-measures, consist of a conglomerate called "dolomitic," because the pebbles of older rocks are cemented together by a red or yellow base of dolomite or magnesian limestone. This conglomerate or breccia, for the imbedded fragments are sometimes angular, occurs in patches over the whole of the downs near Bristol, filling up the hollows and irregularities in the mountain limestone, and being principally composed at every spot of the debris of those rocks on which it immediately rests. At one point we find pieces of coal-shale, in another of mountain limestone, recognizable by its peculiar shells and zoophytes. Fractured bones, also, and teeth of saurians are dispersed through some parts of the breccia.

These saurians (which until the discovery of the *Archegosaurus* in the coal were the most ancient examples of fossil reptiles) are all distinguished by having the teeth implanted deeply in the jaw-bone, and in distinct sockets, instead of being soldered, as in frogs, to a simple alveolar parapet. In the dolomitic conglomerate near Bristol the remains of species of two genera have been found, called *Thecodontosaurus* and *Palæosaurus* by Dr. Riley and Mr. Stutchbury*; the teeth of which are conical, compressed, and with finely serrated edges (figs. 459 and 460.).

Teeth of Saurians. Dolomitic conglomerate; Redland, near Bristol.

Fig. 459.



Tooth of *Palæosaurus platyodon*, nat. size.

Fig. 460.

Tooth of *Thecodontosaurus*, 3 times magnified.

Sir Henry de la Beche has shown that, in consequence of the isolated position of the breccia containing these fossils, it is very difficult to determine to what precise part of the Poikilitic series they belong.† Some observers suspect them to be triassic; but, until the evidence in support of that view is more conclusive, we may continue to hold the opinion of their original discoverers.

In Russia, also, Thecodont saurians of several genera occur, in beds of the Permian age, while others, named *Protorosaurus*, are met with in the Zechstein of Thuringia. This family of reptiles is allied to the living monitor, and its appearance in a primary or paleozoic formation, observes Prof. Owen, is opposed to the doctrine of the progressive development of reptiles from fish, or from simpler to more complex forms; for, if they existed at the present day, these monitors would take rank at the head of the Lacertian order.‡

We learn from the writings of Sir R. Murchison § that in Russia the Permian rocks are composed of white limestone, with gypsum and

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* Geol. Trans., Second Series, vol. v. p. 349., plate 29., figures 2. and 5.

† Memoirs of Geol. Survey of Great Britain, vol. i. p. 268.

‡ Owen, Report on Reptiles, British Assoc., Eleventh Meeting, 1841, p. 197.

§ Russia and the Ural Mountains, 1845; and Siluria, ch. xii. 1854.

white salt; and of red and green grits, occasionally with copper-ore; also magnesian limestones, marlstones, and conglomerates.

The country of Mansfeld, in Thuringia, may be called the classic ground of the Lower New Red, or Magnesian Limestone, or Permian formation, on the Continent. It consists there principally of, first, the Zechstein, corresponding to the upper portion of our English series; and, secondly, the marl-slate, with fish of species identical with those of the bed so called in Durham. This slaty marlstone is richly impregnated with copper-pyrites, for which it is extensively worked. Magnesian limestone, gypsum, and rock-salt occur among the superior strata of this group. At its base lies the Rothliegendes, supposed to correspond with the Inferior or Lower New Red Sandstone above mentioned, which occupies a similar place in England between the marl-slate and coal. Its local name of "Rothliegendes," *red-lyer*, or "Roth-todt-liegendes," *red-dead-lyer*, was given by the workmen in the German mines from its red colour, and because the copper has *died out* when they reach this rock, which is not metalliferous. It is, in fact, a great deposit of red sandstone and conglomerate, with associated porphyry, basaltic trap, and amygdaloid.

Permian Flora. — We learn from the recent investigation of Colonel von Gutbier, that in the Permian rocks of Saxony no less than sixty species of fossil plants have been met with, forty of which have not yet been found elsewhere. Two or three of these, as *Calamites gigas*, *Sphenopteris erosa*, and *S. lobata*, are also met with in the government of Perm in Russia. Seven others, and among them *Neuropteris Loshii*, *Pecopteris arborescens*, and *P. similis*, with several species of *Walchia* (see fig. 461.), a genus of Conifers, called *Lycopodites* by some authors, are common to the coal-measures.

Fig. 461.

Walchia piniformis, Sternb. Permian, Saxony. (Gutbier, pl. x.)
a. branch. *b.* twig of the same. *c.* leaf magnified.

Fig. 462.

Cardiocarpon Ottonis, Gutbier. Permian, Saxony. $\frac{1}{3}$ diam.

Among the genera also enumerated by Colonel Gutbier are the fruit called *Cardiocarpon* (see fig. 462.), *Asterophyllites*, and *Annularia*, so characteristic of the carboniferous period; also *Lepidodendron*, which is common to the Permian of Saxony, Thuringia, and Russia, although not abundant. *Noeggerathia* (see fig. 463.), supposed by A. Brongniart to be allied to *Cycas*, is another link between the Permian and Carboniferous vegetation. Coniferæ, of the Araucarian division, also occur; but these are likewise met with both in older and newer rocks. The plants called *Sigillaria* and *Stigmaria*, so marked a feature in the carboniferous period, are as yet wanting.

Fig. 463.

Noeggerathia cuneifolia. Ad. Brongniart.*

Among the remarkable fossils of the rothliegendes, or lowest part of the Permian in Saxony and Bohemia, are the silicified trunks of tree-ferns called generically *Psaronius.* Their bark was surrounded by a dense mass of air-roots, which often constituted a great addition to the original stem, so as to double or quadruple its diameter. The same remark holds good in regard to certain living extra-tropical arborescent ferns, particularly those of New Zealand.

Psaronites are also found in the uppermost coal of Autun in France, and in the upper coal-measures of the State of Ohio in the United States, but specifically different from those of the rothliegendes. They serve to connect the Permian flora with the more modern portion of the preceding or carboniferous group. Upon the whole, it is evident that the Permian plants approach much nearer to the carboniferous flora than to the triassic; and the same may be said of the Permian fauna.

* Murchison's Russia, vol. ii. pl. A. fig. 3.

CHAPTER XXIV

THE COAL, OR CARBONIFEROUS GROUP.

Carboniferous strata in the south-west of England—Superposition of Coal-measures to Mountain limestone—Departure from this type in North of England and Scotland—Carboniferous series in Ireland—Section in South Wales—Underclays with Stigmaria—Carboniferous Flora—Ferns, Lepidodendra, Equisetaceæ, Calamites, Asterophyllites, Sigillariæ, Stigmariæ—Coniferæ—Sternbergia—Trigonocarpon—Grade of Coniferæ in the Vegetable Kingdom—Absence of Angiosperms—Coal, how formed—Erect fossil trees—Parkfield Colliery—St. Etienne Coal-field—Oblique trees or snags—Fossil forests in Nova Scotia—Rain-prints—Purity of the Coal explained—Time required for the accumulation of the Coal-measures—Brackish-water and marine strata—Crustaceans of the Coal—Origin of Clay-iron-stone.

THE next group which we meet with in the descending order is the Carboniferous, commonly called "The Coal;" because it contains many beds of that mineral, in a more or less pure state, interstratified with sandstones, shales, and limestones. The coal itself, even in Great Britain and Belgium, where it is most abundant, constitutes but an insignificant portion of the whole mass. In the north of England, for example, the thickness of the coal-bearing strata has been estimated by Prof. Phillips at 3000 feet, while the various coal-seams, 20 or 30 in number, do not in the aggregate exceed 60 feet.

The carboniferous formation assumes various characters in different parts even of the British Islands. It usually comprises two very distinct members: 1st, that usually called the Coal-measures, of mixed freshwater, terrestrial, and marine origin, often including seams of coal; 2dly, that named in England the Mountain or Carboniferous Limestone, of purely marine origin, and containing corals, shells, and encrinites.

In the south-western part of our island, in Somersetshire and South Wales, the three divisions usually spoken of by English geologists are:

1. Coal-measures	Strata of shale, sandstone, and grit, with occasional seams of coal, from 600 to 12,000 feet thick.
2. Millstone-grit	A coarse quartzose sandstone passing into a conglomerate, sometimes used for millstones, with beds of shale; usually devoid of coal; occasionally above 600 feet thick.
3. Mountain or Carboniferous limestone	A calcareous rock containing marine shells and corals; devoid of coal; thickness variable, sometimes 900 feet.

The millstone-grit may be considered as one of the coal-sandstones of coarser texture than usual, with some accompanying shales, in which coal-plants are occasionally found. In the north of England some bands of limestone, with pectens, oysters, and other marine shells, occur in this grit, just as in the regular coal-measures, and even a few seams of coal. I shall treat, therefore, of the whole group as consisting of two divisions only, the Coal-measures and the Mountain Limestone. The latter is found in the southern British coal-fields, at the base of the system, or immediately in contact with the subjacent Old Red Sandstone; but as we proceed northwards to Yorkshire and Northumberland it begins to alternate with true coal-measures, the two deposits forming together a series of strata about 1000 feet in thickness. To this mixed formation succeeds the great mass of genuine mountain limestone.* Farther north, in the Fifeshire coal-field in Scotland, we observe a still wider departure from the type of the south of England, or a more complete intercalation of dense masses of marine limestones with sandstones and shales containing coal.

In Ireland a series of shales and slates, constituting the base of the Mountain Limestone, attain so great a thickness, often upwards of 1000 feet, as to be classed as a separate division. Under these slates is a Yellow Sandstone, also considered as carboniferous from its marine fossils, although passing into the underlying Devonian. A similar sandstone of much less thickness occurs in the same position in Gloucestershire and South Wales.

The following are the subdivisions adopted in the geological map of Ireland, constructed by Mr. Griffiths:—

	Thickness in Feet.
1. Coal-measures, Upper and Lower - - -	1000 to 2200
2. Millstone-grit - - - - -	350 to 1800
3. Mountain limestone, Upper, Middle (or Calp), and Lower - - - - - -	1200 to 6400
4. Carboniferous slate - - - - -	700 to 1200
5. Yellow sandstone (of Mayo, &c.) with shales and limestone - - - - - -	400 to 2000

COAL-MEASURES.

In South Wales the coal-measures have been ascertained by actual measurement to attain the extraordinary thickness of 12,000 feet; the beds throughout, with the exception of the coal itself, appearing to have been formed in water of moderate depth, during a slow, but perhaps intermittent, depression of the ground, in a region to which rivers were bringing a never-failing supply of muddy sediment and sand. The same area was sometimes covered with vast forests, such as we see in the deltas of great rivers in warm climates, which are liable to be submerged beneath fresh or salt water should the ground sink vertically a few feet.

In one section near Swansea, in South Wales, where the total thickness of strata is 3246 feet, we learn from Sir H. De la Beche that there are ten principal masses of sandstone. One of these is

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* Sedgwick, Geol. Trans., Second Series, vol. iv.; and Phillips, Geol. of Yorksh. part 2.

500 feet thick, and the whole of them make together a thickness of 2125 feet. They are separated by masses of shale, varying in thickness from 10 to 50 feet. The intercalated coal-beds, sixteen in number, are generally from 1 to 5 feet thick, one of them, which has two or three layers of clay interposed, attaining 9 feet.* At other points in the same coal-field the shales predominate over the sandstones. The horizontal extent of some seams of coal is much greater than that of others, but they all present one characteristic feature, in having, each of them, what is called its *underclay.* These underclays, co-extensive with every layer of coal, consist of arenaceous shale, sometimes called fire-stone, because it can be made into bricks which stand the fire of a furnace. They vary in thickness from 6 inches to more than 10 feet; and Mr. Logan first announced to the scientific world in 1841 that they were regarded by the colliers in South Wales as an essential accompaniment of each of the one hundred seams of coal met with in their coal-field. They are said to form the *floor* on which the coal rests; and some of them have a slight admixture of carbonaceous matter, while others are quite blackened by it.

All of them, as Mr. Logan pointed out, are characterized by inclosing a peculiar species of fossil vegetable called *Stigmaria,* to the exclusion of other plants. It was also observed that, while in the overlying shales or "roof" of the coal, ferns and trunks of trees abound without any *Stigmariæ,* and are flattened and compressed, those singular plants of the underclay very often retain their natural forms, branching freely, and sending out their slender leaf-like rootlets, formerly thought to be leaves, through the mud in all directions. Several species of *Stigmaria* had long been known to botanists, and described by them, before their position under each seam of coal was pointed out, and before their true nature as the roots of trees was recognized. It was conjectured that they might be aquatic, perhaps floating plants, which sometimes extended their branches and leaves freely in fluid mud, and which were finally enveloped in the same mud.

CARBONIFEROUS FLORA.

These statements will suffice to convince the reader that we cannot arrive at a satisfactory theory of the origin of coal until we understand the true nature of *Stigmaria;* and in order to explain what is now known of this plant, and of others which have contributed by their decay to produce coal, it will be necessary to offer a brief preliminary sketch of the whole carboniferous flora, an assemblage of fossil plants with which we are better acquainted than with any other which flourished antecedently to the tertiary epoch. It should also be marked that Göppert has ascertained that the remains of every family of plants scattered through the coal-measures are sometimes met with in the pure coal itself, a fact which adds greatly to the geological interest attached to this flora.

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* Memoirs of Geol. Survey, vol. i. p. 195.

Ferns. — The number of species of carboniferous plants hitherto described amounts, according to M. Ad. Brongniart, to about 500. These may perhaps be a fragment only of the entire flora, but they are enough to show that the state of the vegetable world was then extremely different from that now prevailing. We are struck at the first glance with the similarity of many of the ferns to those now living, and the dissimilarity of almost all the other fossils except the coniferæ. Among the ferns, as in the case of *Pecopteris* for example (fig. 464.), it is not always easy to decide whether they should be referred to different genera from those established for the classification of living species; whereas, in regard to most of the other contemporary tribes, with the exception of the coniferæ, it is often difficult to guess the family, or even the class, to which they belong. The ferns of the carboniferous period are generally without organs of fructification, but in some specimens these are well preserved. In the general absence of such characters, they have been divided into genera distinguished chiefly by the branching of the fronds, and the way in which the veins of the leaves are disposed. The larger portion are supposed to have been of the size of ordinary

Fig. 464.

Pecopteris lonchitica.
(Foss. Flo. 153.)

Fig. 465.

a. Sphenopteris crenata.
b. Part of the same, magnified.
(Foss. Flo. 101.)

Fig. 466.

Caulopteris primæva, Lindley.

European ferns, but some were decidedly arborescent, especially the group called *Caulopteris*, by Lindley, and the *Psaronius* of the upper or newest coal-measures, before alluded to (p. 360.).

All the recent tree-ferns belong to one tribe (*Polypodiaceæ*), and to a small number only of genera in that tribe, in which the surface of the trunk is marked with scars, or cicatrices, left after the fall of the fronds. These scars resemble those of *Caulopteris* (see fig. 466.). No less than 250 ferns have already been obtained from the coal-strata; and, even if we make some reduction on the ground of varieties which have been mistaken, in the absence of their fructification, for species, still the result is singular, because the whole of Europe affords at present no more than 60 indigenous species.


Fig. 468.

Fig. 469.

Fig. 467.

Living tree-ferns of different genera. (Ad. Brong.)

Fig. 467. Tree-fern from Isle of Bourbon.
Fig. 468. *Cyathea glauca*, Mauritius.
Fig. 469. Tree-fern from Brazil.

Lepidodendron.—About 40 species of fossil plants of the Coal have been referred to this genus. They consist of cylindrical stems or trunks, covered with leaf-scars. In their mode of branching, they are always dichotomous (see fig. 471.). They are considered by Brongniart and Hooker to belong to the *Lycopodiaceæ*, plants of this family bearing cones, with similar sporangia and spores (fig. 474.). Most of them grew to the size of large trees. The figures 470—472. represent a fossil *Lepidodendron*, 49 feet long, found in Jarrow Colliery, near Newcastle, lying in shale parallel to the planes of stratification. Fragments of others, found in the same shale, indicate, by the size of the rhomboidal scars which cover them, a still greater magnitude. The living club-mosses, of which there are about 200 species, are abundant in tropical climates, where one species is sometimes met with attaining a height of 3 feet. They usually creep on the ground, but some stand erect, as the *L. densum* from New Zealand (fig. 473.).

Fig. 470.

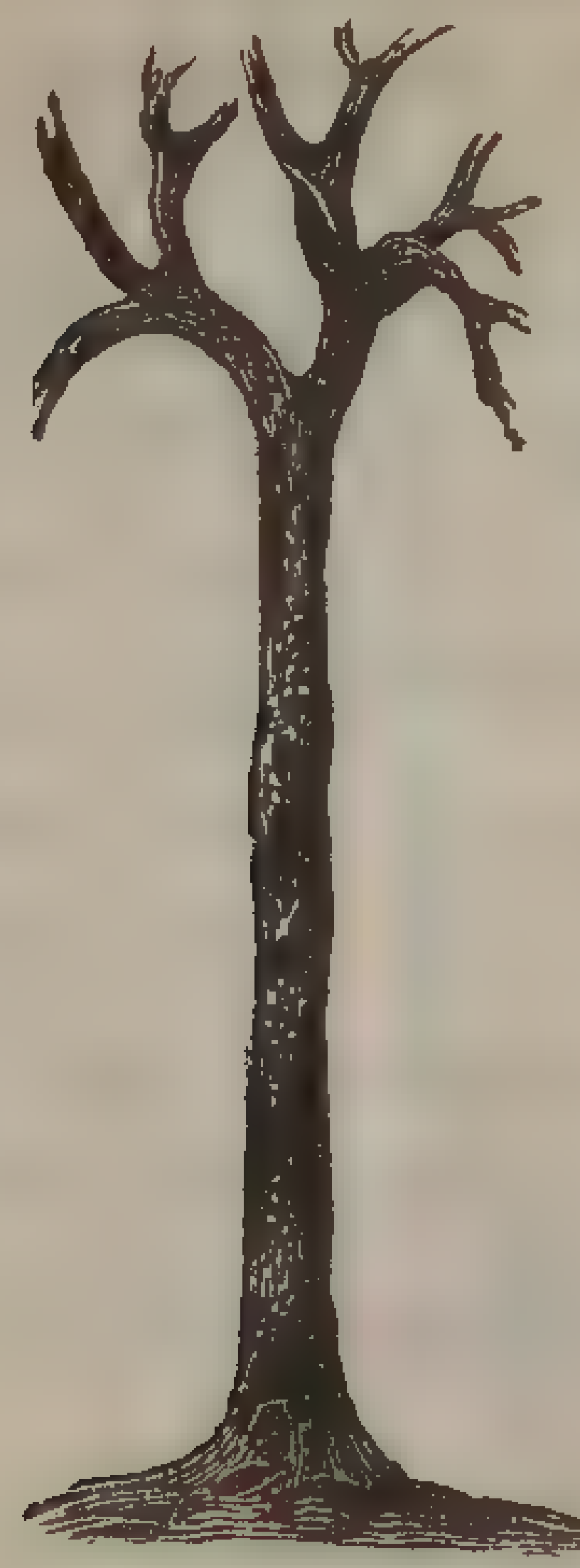
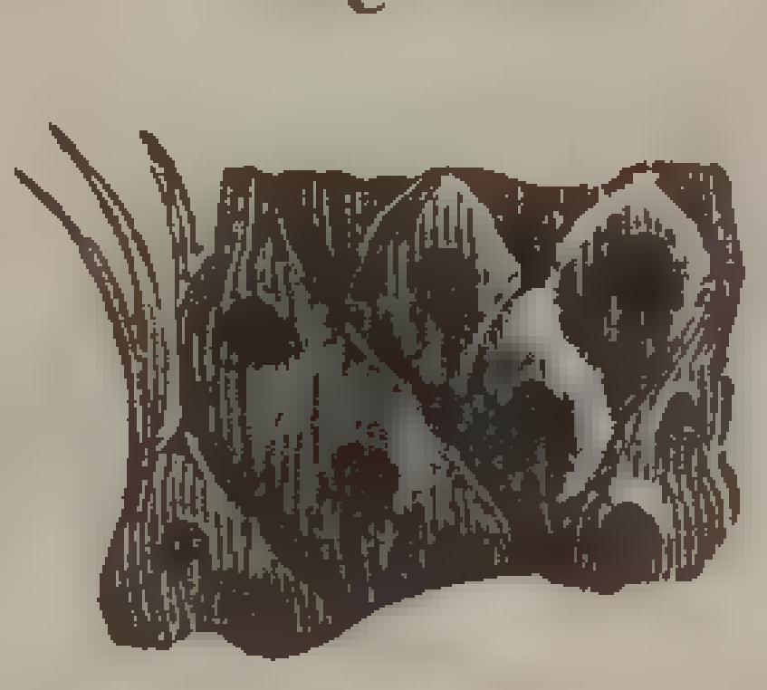


Fig. 471.

Fig. 472.



Lepidodendron Sternbergii. Coal-measures, near Newcastle.

Fig. 470. Branching trunk, 49 feet long, supposed to have belonged to *L. Sternbergii.* (Foss. Flo. 203.)

Fig. 471. Branching stem with bark and leaves of *L. Sternbergii.* (Foss. Flo. 4.)

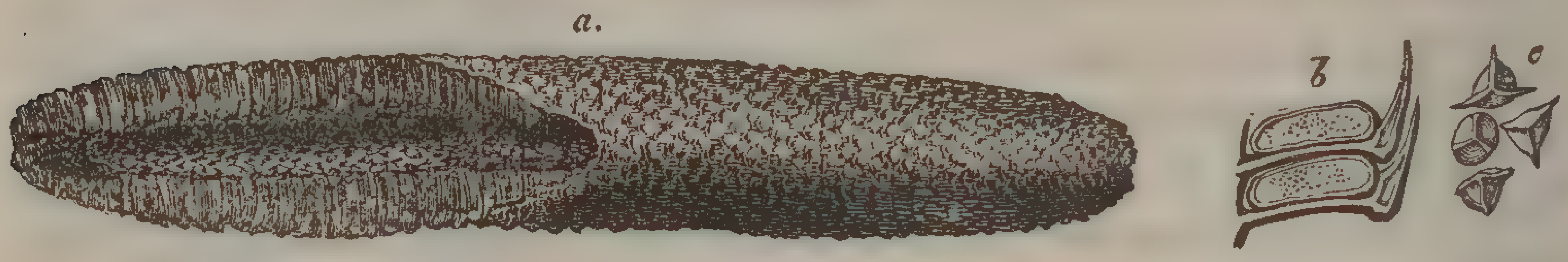
Fig. 472. Portion of same nearer the root; natural size. (Ibid.)

Fig. 473.

a. Lycopodium densum; banks of R. Thames, New Zealand.
b. branch, natural size. *c.* part of same, magnified.

In the carboniferous strata of Coalbrook Dale, and in many other coal-fields, elongated cylindrical bodies, called fossil cones, named *Lepidostrobus* by M. Adolphe Brongniart, are met with. (See fig. 474.) They often form the nucleus of concretionary balls of clay-

Fig. 474.



a. Lepidostrobus ornatus, Brong. Shropshire; half natural size
b. Portion of a section showing the large sporangia in their natural position, and each supported by its bract or scale.
c. Spores in these sporangia, highly magnified. (Hooker, Mem. Geol. Survey, vol. ii. part 2. p. 440.)

ironstone, and are well preserved, exhibiting a conical axis, around which a great quantity of scales were compactly imbricated. The opinion of M. Brongniart is now generally adopted, that the *Lepidostrobus* is the fruit of *Lepidodendron;* indeed, it is not uncommon in Coalbrook Dale and elsewhere to find these *strobili* or fruits terminating the tip of a branch of a well characterized *Lepidodendron.*

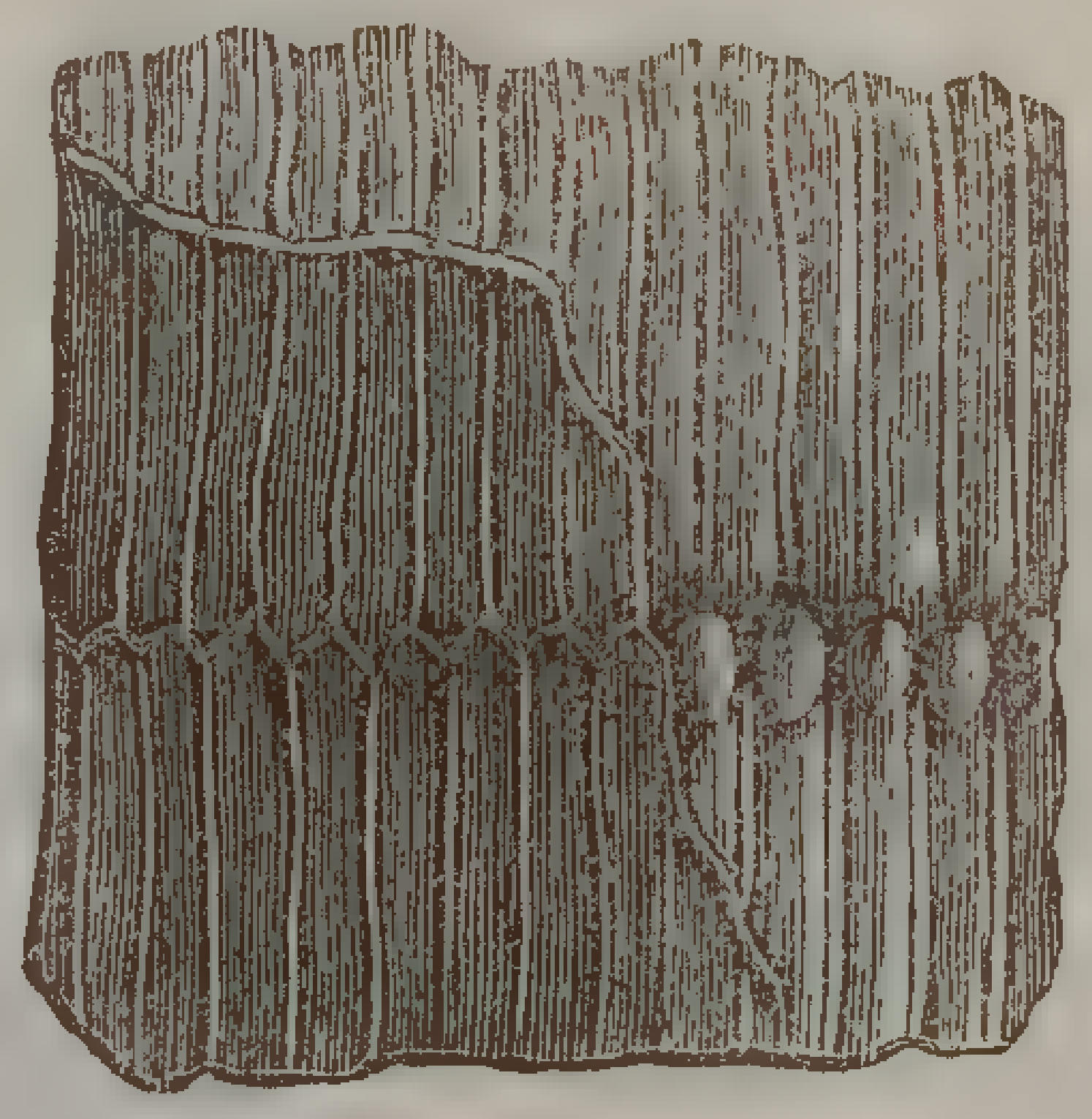
Equisetaceæ. — To this family belong two fossil species of the Coal, one called *Equisetum infundibuliforme* by Brongniart, and found also in Nova Scotia, which has sheaths, regularly toothed, ribbed, and overlapping like those on the young fertile stems of *Equisetum fluviatile.* It was much larger than any living "Horsetail." The *Equisetum giganteum,* discovered by Humboldt and Bonpland in South America, attained a height of about 5 feet, the stem being an inch in diameter; but more recently Gardner has met with one in Brazil 15 feet high, and Meyen gives the height of *E. Bogotense* in Chili as 15 to 20 feet.

Calamites. — The fossil plants so called were originally classed by most botanists as cryptogamous, being regarded as gigantic *Equiseta;* for, like the common "horsetail," they usually exhibit little more than hollow jointed stems, furrowed externally. (See figs. 475, 476, 477.)

Fig. 475.

Calamites cannæformis, Schlot. (Foss. Flo. 79.) Common in English coal.

Fig. 476.



Calamites Suckowii, Brong.; natural size. Common in coal throughout Europe.

Fig. 477.

Radical termination of a Calamite. Nova Scotia.

Mr. Salter stated to me many years ago his conviction that the calamite as frequently represented by paleontologists was in an inverted position, and that the conical part given as the top of the stem was in truth the root. This point Mr. Dawson and I had opportunities of testing in Nova Scotia, where we saw many erect calamites, having their radical termination as in the annexed figure (fig. 477.). The scars, from which whorls of vessels have proceeded, are observed at the upper, not the lower end of each joint or internode.* The specimen, fig. 475., therefore, is no doubt the lower end of the plant, and I have therefore reversed its position as given in the work of Lindley and Hutton.

M. Adolphe Brongniart, following up the discoveries of Germar and Corda, has shown in his "Genres de Végétaux Fossiles," 1849, that many Calamites cannot belong to the *Equiseta,* nor probably to any tribe of flowerless plants. He conceives that they are more

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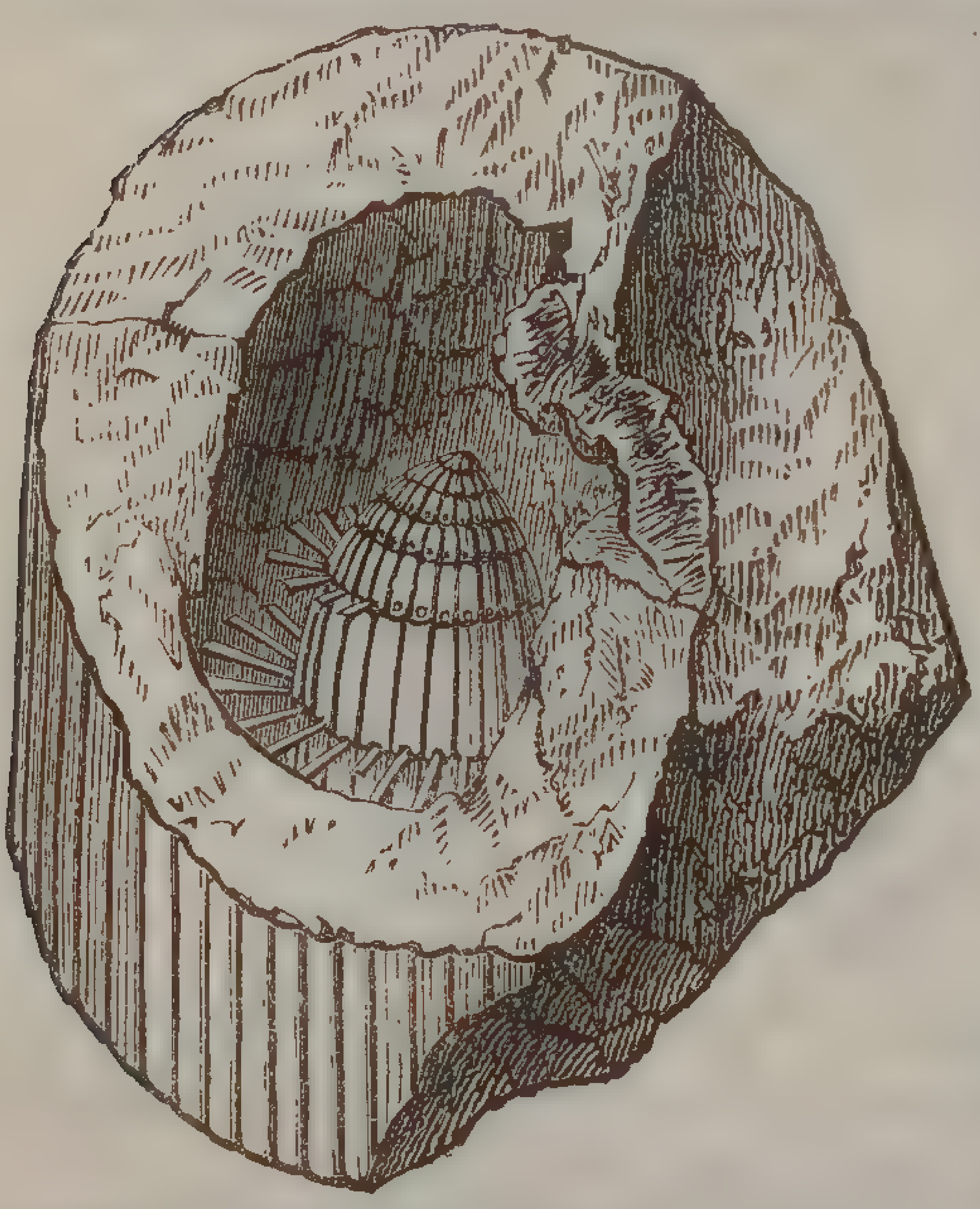
* See Dawson, Geol. Quart. Journal, 1854, vol. x. p. 35.

nearly allied to the Gymnospermous Dicotyledons. They possessed a central pith, surrounded by a ligneous cylinder, which was divided by regular medullary rays. This cylinder was surrounded in turn by a thick bark. Of fossil stems having this structure Brongniart formed his genus *Calamodendron*, which includes many species referred by Cotta, Petzholdt, and Unger to the genus *Calamitea.* The *Calamodendron* is described as smooth externally, its pith being articulated and marked with deep external vertical striæ, agreeing in short with what geologists commonly call a Calamite. Since the appearance of Brongniart's essay, Mr. E. W. Binney has made many important discoveries on the same subject; and Mr. J. S. Dawes has published (Quart. Journ. Geol. Soc. Lond. 1851, vol. vii. p. 196.) a more complete account of this singular fossil. Their views have been confirmed by Prof. Williamson of Manchester, who has communicated to me a specimen, figured in the annexed cut (fig. 478.), in which we see an internal pith answering in character to the Calamodendron and yet having outside of it another jointed cylinder vertically grooved on its outer surface, so that in the same stem we have one calamite enveloping another. Yet that they both formed part of the same plant is proved by the following circumstances: — 1st. Near each articulation of the pith radiating spokes are seen to proceed and penetrate the ligneous zone. One complete whorl or circle of these radii is visible in the annexed figure near the bottom of the hollow cavity, whilst another and superior whorl is incomplete; several radii, corresponding to the first, remaining, while the rest have been broken away, their place being shown by scars which they have left. 2dly. In addition to these whorls, called medullary by Prof. Williamson, there are seen in other specimens a set of true or ordinary medullary rays. 3dly. The woody zone, penetrated both by the spoke-like vessels before-mentioned and by the medullary rays, is usually reduced to brown carbonaceous matter, preserving merely a tendency to break in longitudinal slips, but in some specimens its fibrous tissue is retained, and resembles that of *Dadoxylon.* 4thly. Outside of this zone again is another cylinder, supposed to have been originally a thick cellular bark, nearly equal to one-third of the whole stem in diameter, grooved and jointed externally like the pith.

Fig. 478.



Portion of a *Calamite*, near the base, showing the external cylinder, connected by radiating vessels with the cast of the pith. Its position inverted to allow the light to enter the cavity.
Communicated by Prof. W. C. Williamson.

In conclusion, I may remark that these discoveries make it more and more doubtful to what family the greater number of Calamites should be referred. Their internal organization, says Prof. Williamson, was very peculiar; for while they exhibit remarkable affinities with gymnospermous dicotyledons, the arrangement of their tissues differs widely from that of all known forms of gymnosperms.

Asterophyllites.—The graceful plant represented in the annexed figure is supposed by M. Brongniart to be a branch of the *Calamodendron*, and he infers from its pith and medullary rays that it was dicotyledonous. It appears to have been allied, by the nature of its tissue, to the gymnogens, and to *Sigillaria*. But under the head of *Asterophyllites* many vegetable fragments have been grouped which probably belong to different genera. They have, in short, no character in common, except that of possessing narrow, verticillate, one-ribbed leaves. Dr. Newberry, of Ohio, has discovered in the coal of that country fossil stems which in their upper part bear wedge-shaped leaves corresponding to *Sphenophyllum*, while below the leaves are stalk-like and capillary, and would have been called *Asterophyllites* if found detached. From this he infers that *Sphenophyllum* was an aquatic plant, the superior and floating leaves of which were broad, and possessed a compound nervation, while the inferior or submersed leaves were linear and one-ribbed. "This supposition," he adds, "is further strengthened by the extreme length and tenuity of the branches of this apparently herbaceous plant, which would seem to have required the support of a denser medium than air."*

Fig. 479.

Asterophyllites foliosa. (Foss. Flo. 25.) Coal-measures, Newcastle.

Sigillaria.—A large portion of the trees of the carboniferous period belonged to this genus, of which about thirty-five species are known. The structure, both internal and external, was very peculiar, and, with reference to existing types, very anomalous. They were formerly referred, by M. Ad. Brongniart, to ferns, which they resemble in the scalariform texture of their vessels, and, in some degree, in the form of the cicatrices left by the base of the leaf-

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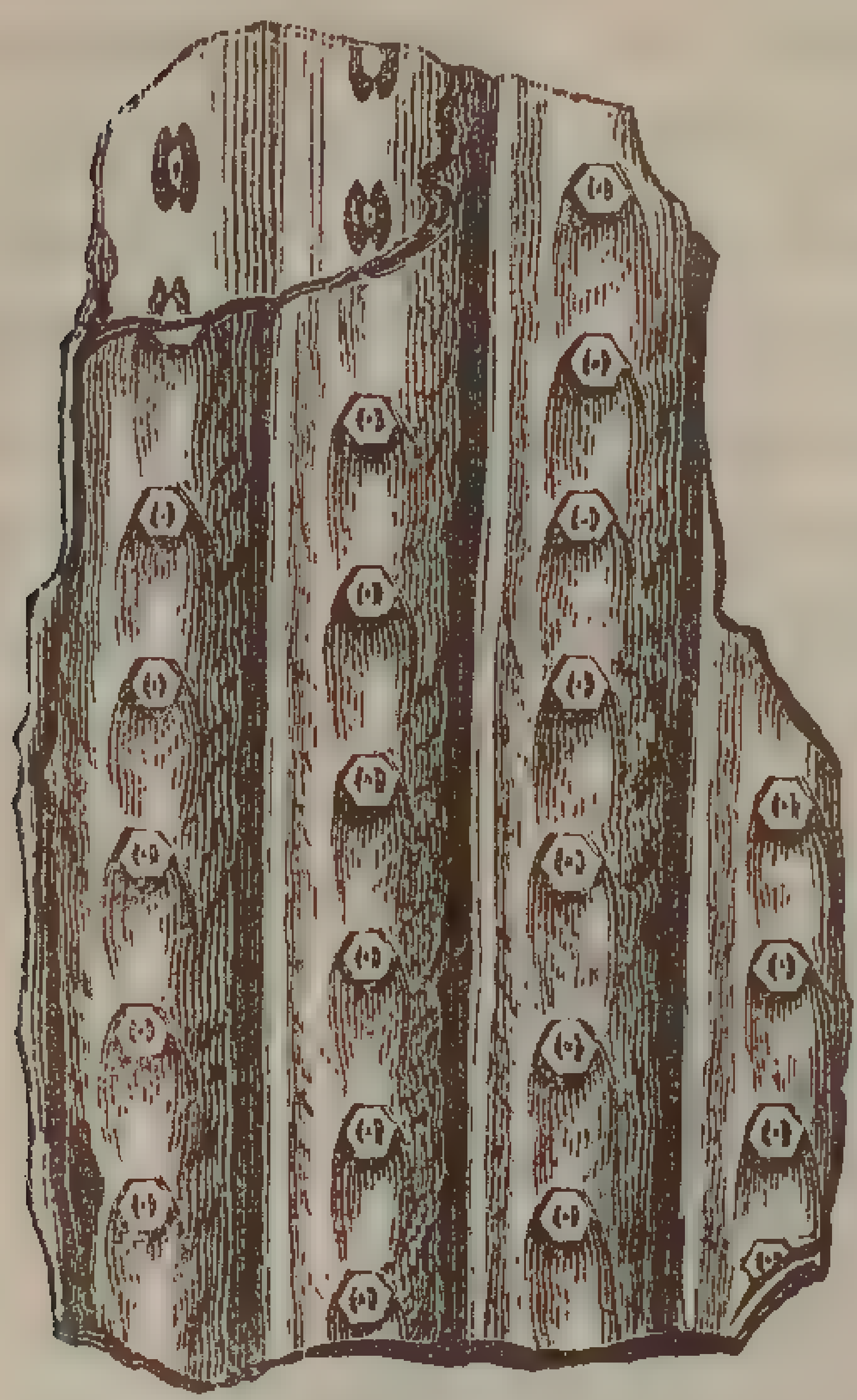
* Annals of Science, Cleveland, Ohio, 1853, p. 97.

stalks which have fallen off (see fig. 480.). But with these points of analogy to cryptogamia, they combine an internal organization much resembling that of cycads, and some of them are ascertained to have had long linear leaves, quite unlike those of ferns. They grew to a great height, from 30 to 60, or even 70 feet, with regular cylindrical stems, and without branches, although some species were dichotomous towards the top. Their fluted trunks, from 1 to 5 feet in diameter, appear to have decayed more rapidly in the interior than externally, so that they became hollow, when standing; and when thrown prostrate on the mud, they were squeezed down and flattened. Hence, we find the bark of the two opposite sides (now converted into bright shining coal) to constitute two horizontal layers, one upon the other, half an inch, or an inch, in thickness. These same trunks, when they are placed obliquely or vertically to the planes of stratification, retain their original rounded form, and are uncompressed, the cylinder of bark having been filled with sand, which now affords a cast of the interior.

Fig. 480.

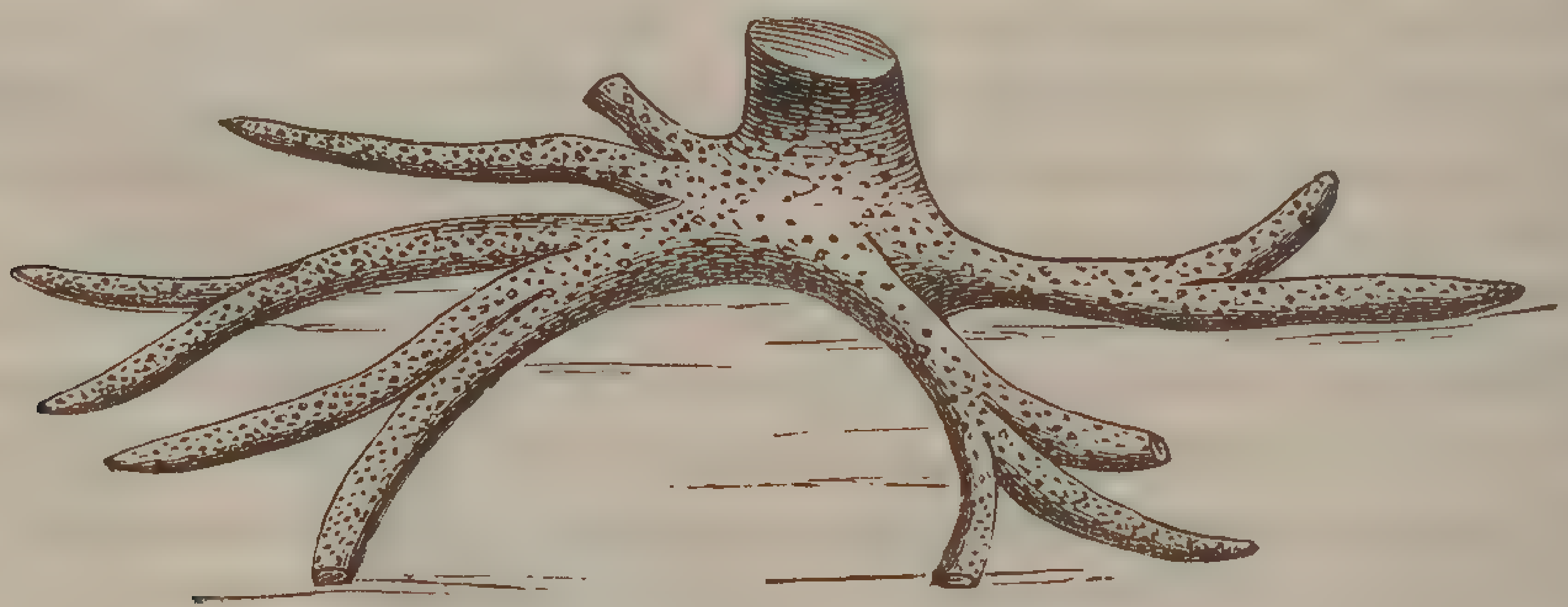


Sigillaria lævigata, Brong.

Dr. Hooker still inclines to the belief that the *Sigillariæ* may have been cryptogamous, though more highly developed than any flowerless plants now living. The scalariform structure of their vessels agrees precisely with that of ferns.

Stigmaria. — This fossil, the importance of which has already been pointed out, was formerly conjectured to be an aquatic plant. It is now ascertained to be the root of *Sigillaria.* The connection of the roots with the stem, previously suspected, on botanical grounds, by Brongniart, was first proved, by actual contact, in the Lancashire coal-field, by Mr. Binney. The fact has lately been shown, even more distinctly, by Mr. Richard Brown, in his description of the

Fig. 481.



Stigmaria attached to a trunk of *Sigillaria.**

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* The trunk in this case is referred by Mr. Brown to *Lepidodendron*, but his illustrations seem to show the usual markings assumed by *Sigillaria* near its base.

Stigmariæ occurring in the underclays of the coal-seams of the Island of Cape Breton, in Nova Scotia.

In a specimen of one of these, represented in the annexed figure (fig. 481.), the spread of the roots was 16 feet, and some of them sent out rootlets, in all directions, into the surrounding clay.

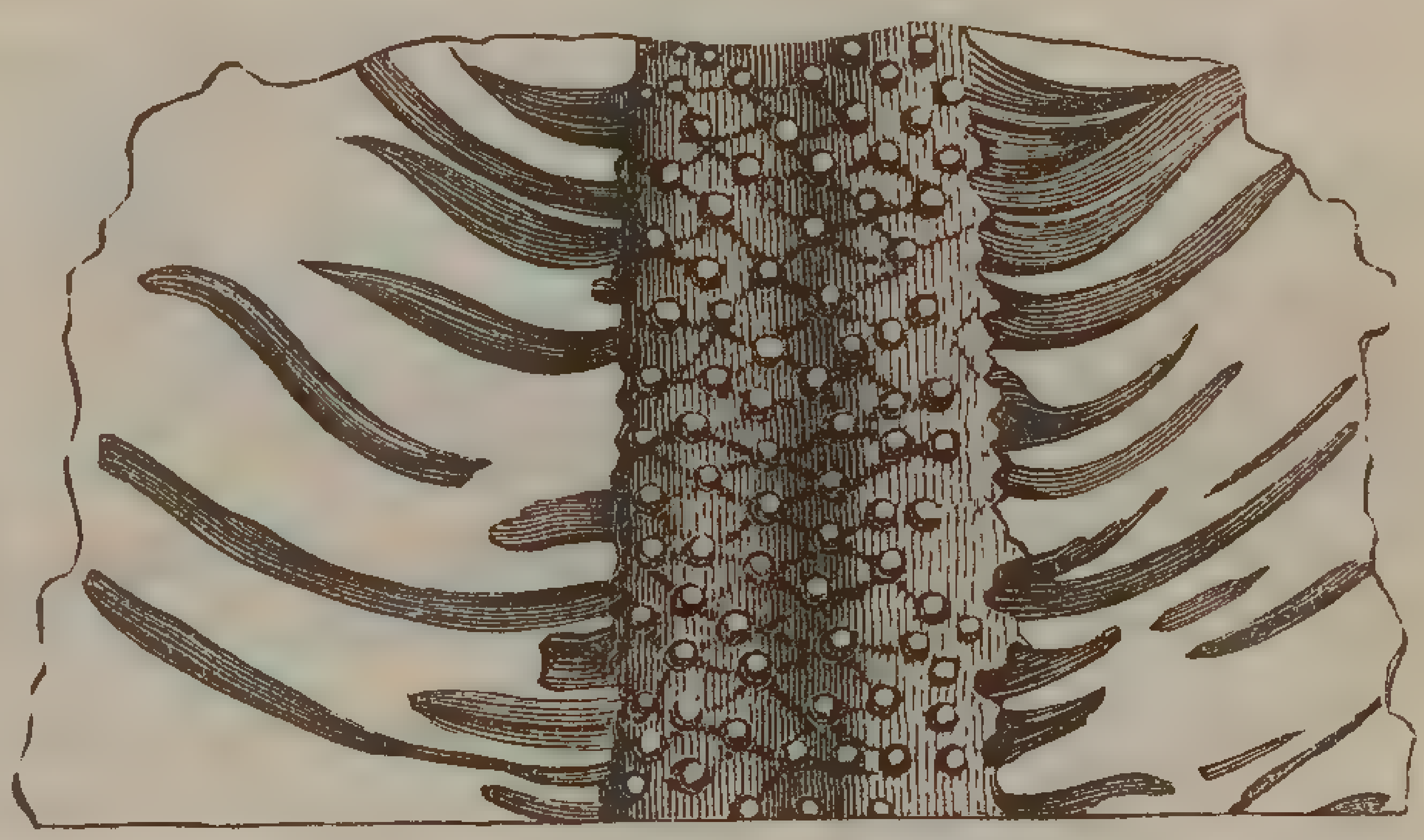
In the sea-cliffs of the South Joggins in Nova Scotia I examined several erect *Sigillariæ*, in company with Mr. Dawson, and we found that from the lower extremities of the trunk they sent out *Stigmariæ* as roots. All the stools of the fossil trees dug out by us divided into four parts, and these again bifurcated, forming eight roots, which were also dichotomous when traceable far enough.

The manner of attachment of the fibres to the stem resembles that of a ball and socket joint, the base of each rootlet being concave, and fitting on to a tubercle (see figs. 482. and 483.). Rows of these tubercles are arranged spirally round each root, which has always a medullary cavity and woody texture, much resembling that of *Sigillaria*, the structure of the vessels being, like it, scalariform.

Fig. 482.

Surface of another individual of same species, showing form of tubercles. (Foss. Flo. 34.)

Fig. 483.



Stigmaria ficoides, Brong. One fourth of nat. size. (Foss. Flo. 32.)

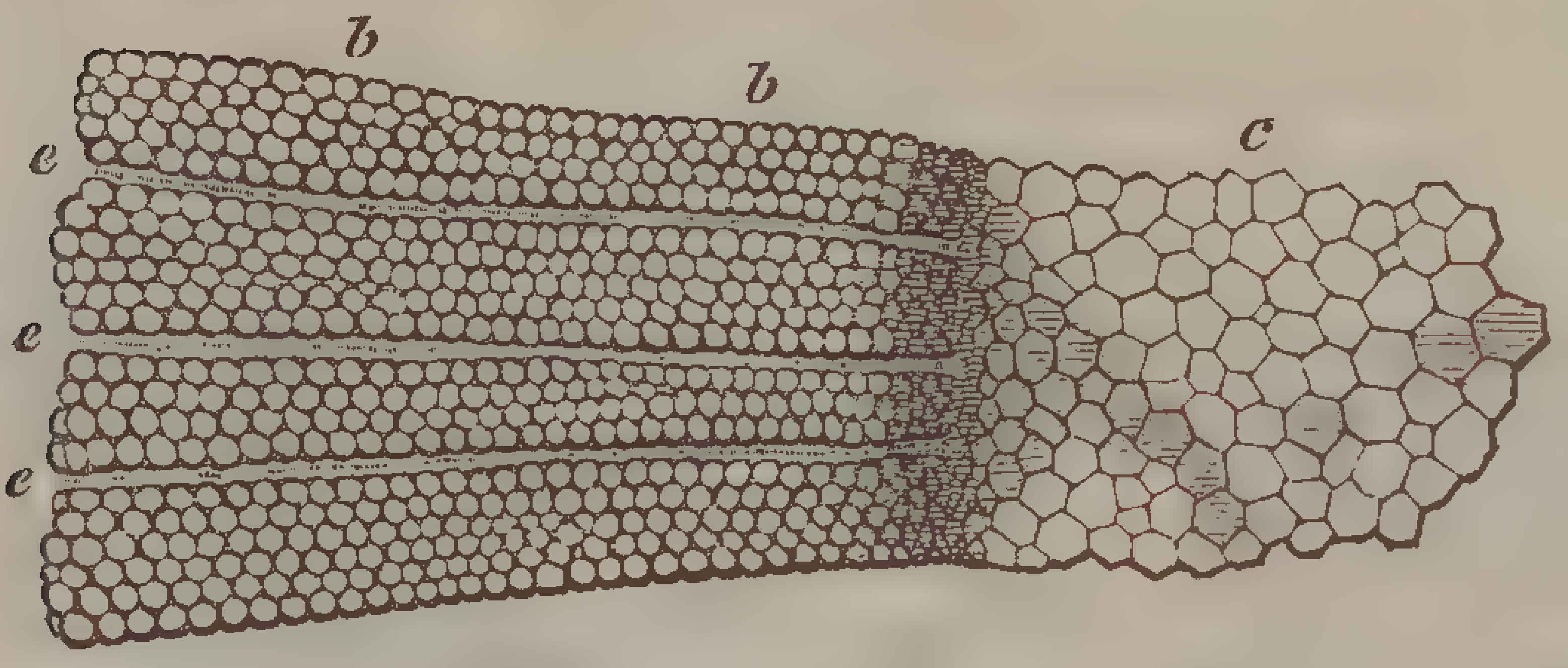
Coniferæ.—The coniferous trees of this period are referred to five genera; the woody structure of some of them showing that they were allied to the Araucarian division of pines, more than to any of our common European firs. Some of their trunks exceeded 44 feet in height. Many, if not all of them, seem to have differed from living *Coniferæ* in having large piths; for Professor Williamson has demonstrated the fossil of the coal-measures called *Sternbergia* to be the pith of these trees, or rather the cast of cavities formed by the shrinking or partial absorption of the original medullary axis (see figs. 484. and 485.). This peculiar type of pith is observed in living plants of very different families, such as the common Walnut and the White Jasmine, in which the pith becomes so reduced as simply to form a thin lining of the medullary cavity, across which transverse plates of pith extend horizontally, so as to divide the cylindrical hollow into discoid interspaces. When these last have been filled up with inorganic matter, they constitute an axis to which, before their true nature was known, the provisional name of *Sternbergia* (*d*, *d*, fig. 484.) was given.

Fig. 484.

Fig. 484. Fragment of coniferous wood, *Dadoxylon*, Endlicher, fractured longitudinally; from Coalbrook Dale. W. C. Williamson.*

a. bark.
b. woody zone or fibre (pleurenchyma).
c. medulla or pith.
d. cast of hollow pith, or "Sternbergia."

Fig. 485.



Magnified portion of fig. 484.; transverse section.
c. pith. *b*, *b*. woody fibre. *e*, *e*. medullary rays.

In the above specimen the structure of the wood (*b*, figs. 484. and 485.) is coniferous, and the fossil is referable to Endlicher's fossil genus *Dadoxylon*.

The fossil named *Trigonocarpon* (figs. 486. and 487.), formerly supposed to be the fruit of a palm, may now, according to Dr. Hooker, be referred, like the *Sternbergia*, to the *Coniferæ*. Its geological importance is great, for so abundant is it in the Coal Measures, that in certain localities the fruit of some species may be procured by the bushel; nor is there any part of the formation where they do not occur, except the underclays and limestone. The sandstone, ironstone, shales, and coal itself, all contain them. Mr. Binney

Fig. 486.

Trigonocarpum ovatum, Lindley and Hutton. Peel Quarry, Lancashire.

Fig. 487.

Trigonocarpum olivæforme, Lindley, with its fleshy envelope. Felling Colliery, Newcastle.

Manchester Philos. Mem. vol. ix. 1851.

has at length found in the clay-ironstone of Lancashire several specimens displaying structure, and from these, says Dr. Hooker, we learn that the *Trigonocarpon* belonged to that large section of existing coniferous plants which bear fleshy solitary fruits, and not cones. It resembled very closely the fruit of the Chinese genus *Salisburia*, one of the Yew tribe, or Taxoid conifers. In five of the fossil specimens there is evidence of four distinct integuments, and of a large internal cavity filled with carbonate of lime and magnesia, and probably once occupied by the albumen and embryo of the seed. The general form of the fossil when perfect is an elongated ovoid, rather larger than a hazle-nut. The exterior integument is very thick and cellular, and was no doubt once fleshy (see fig. 487.). It alone is produced beyond the seed, and forms the beak. The second coat was thinner, but hard, and marked by three ridges. This coat, being all that commonly remains in a fossil state, has suggested the name of *Trigonocarpon*. Within this were the third and fourth coats, both of which are very delicate membranes, and may possibly have been two plates belonging to one membrane.

Grade of the Carboniferous Flora.—On the whole, these fruits, says Dr. Hooker, are referable to "a highly developed type, exhibiting extensive modifications of elementary organs for the purpose of their adaptation to special functions, and these modifications are as great, and the adaptation as special, as any to be found amongst analogous fruits in the existing vegetable world."* Professor Williamson, in his paper on *Sternbergia*, has likewise remarked that its structure was complex, and that "at a period so early as the carboniferous all the now-existing forms of vegetable tissue appear to have been created." These observations deserve notice, because a question has arisen—whether the *Coniferæ* hold a high or a low position among flowering plants,—a point bearing directly on the theory of progressive development. By some botanists all the Gymnospermous Dicotyledons are regarded as inferior in grade to the Angiosperms. Others hold, with Dr. Hooker, that the Gymnosperms are not inferior in rank, having every typical character of the dicotyledons highly developed. Thus Coniferæ have flowers, and are propagated by seeds which are developed through the mutual action of the stamens and ovules; they have distinct embryos, and germinate in a definite manner. The seed-vessel (or ovary) is not closed, but this is also the case in some genera of angiosperms, in which the ovary is open before or after impregnation, so that this character cannot be relied on as constituting a fundamental difference in structural development. The Coniferæ are exogenous, and have the same distinctions of pith, wood, bark, and medullary rays as have the angiospermous trees. Whether the woody fibre with discs characteristic of Coniferæ be a more or a less complex tissue than the spiral vessels, is a controverted point. As the spiral vessels occur in the young shoots, and are lost in the

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* Proceedings of the Royal Society, vol. vii. March, 1854, p. 28.

mature growth of some plants, and as they appear in many acrogens, they do not seem to mark a high development. In fine, there is much ambiguity in deciding what should or should not be called *high* or *low* in vegetable structure, and physiologists entertain very different abstract ideas as to the perfection of certain organs and their relative functional importance, even where the function is clearly ascertained. It is enough for the geologist to know, that fossil Coniferæ abound in the oldest rocks yielding a considerable number of vegetable remains, and that plants of this order lay claim, if not to the highest, at least to so high a place in the scale of vegetable life, as to preclude us from characterizing the carboniferous flora as consisting of imperfectly developed plants.

Although our data are confessedly too defective to entitle us to generalize respecting the entire vegetable creation of this era, yet we may affirm that so far as it is known it differed widely from any flora now existing. The comparative rarity of Monocotyledons and of Dicotyledonous Angiosperms seems clear, and the abundance of Ferns and Lycopods may justify Adolphe Brongniart in calling the primary periods the age of Acrogens.* ("Le règne des Acrogens.") As to the Sigillariæ and Calamites, they seem to have been distinct from all tribes of now-existing plants. That the abundance of ferns implies a moist atmosphere, is admitted by all botanists; but no safe conclusion, says Hooker, can be drawn from the Coniferæ alone, as they are found in hot and dry and in cold and dry climates, in hot and moist and in cold and moist regions. In New Zealand the Coniferæ attain their maximum in numbers, constituting $\frac{1}{62}$nd part of all the flowering plants; whereas in a wide district around the Cape of Good Hope they do not form $\frac{1}{1600}$th of the phenogamic flora. Besides the conifers, many species of ferns flourish in New Zealand, some of them arborescent, together with many lycopodiums; so that a forest in that country may make a nearer approach to the carboniferous vegetation than any other now existing on the globe.

Angiosperms.—Some of the grass-like leaves termed *Poacites*, having fine longitudinal striæ, are conjectured to belong to Monocotyledons; but the determination is doubtful, as some of them may be the leaves of *Lepidodendra*, others the stems of Ferns. The curious plants called *Antholithes* by Lindley have usually been considered to be flower-spikes, having what seems a calyx and linear petals (see fig. 488.). But Dr. Hooker suggests that these may be rather tufts of scarcely opened buds with the young leaves just bursting. He suggests that they may be coniferous, although he cannot connect them with any known fossil conifer.

Fig. 488.

Antholithes. Felling Colliery, Newcastle.

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* For terminology of classification of plants, see above, note, p. 267.

Coal, how formed — Erect trees. — I shall now consider the manner in which the above-mentioned plants are imbedded in the strata, and how they may have contributed to produce coal. Professor Göppert, after examining the fossil vegetables of the coal-fields of Germany, has detected, in beds of pure coal, remains of plants of every family hitherto known to occur fossil in the coal. Many seams, he remarks, are rich in *Sigillariæ*, *Lepidodendra*, and *Stigmariæ*, the latter in such abundance, as to appear to form the bulk of the coal. In some places, almost all the plants were calamites, in others ferns.* "Some of the plants of our coal," says Dr. Buckland, "grew on the identical banks of sand, silt, and mud which, being now indurated to stone and shale, form the strata that accompany the coal; whilst other portions of these plants have been drifted to various distances from the swamps, savannahs, and forests that gave them birth, particularly those that are dispersed through the sandstones, or mixed with fishes in the shale beds." "At Balgray, three miles north of Glasgow," says the same author, "I saw in the year 1824, as there still may be seen, an unequivocal example of the stumps of several stems of large trees, standing close together in their native place, in a quarry of sandstone of the coal-formation." †

Between the years 1837 and 1840, six fossil trees were discovered in the coal-field of Lancashire, where it is intersected by the Bolton railway. They were all in a vertical position, with respect to the plane of the bed, which dips about 15° to the south. The distance between the first and the last was more than 100 feet, and the roots of all were imbedded in a soft argillaceous shale. In the same plane with the roots is a bed of coal, eight or ten inches thick, which has been ascertained to extend across the railway, or to the distance of at least ten yards. Just above the covering of the roots, yet beneath the coal-seam, so large a quantity of the *Lepidostrobus variabilis* was discovered inclosed in nodules of hard clay, that more than a bushel was collected from the small openings around the base of the trees (see figure of this genus, p. 366.). The exterior trunk of each was marked by a coating of friable coal, varying from one quarter to three quarters of an inch in thickness; but it crumbled away on removing the matrix. The dimensions of one of the trees is 15½ feet in circumference at the base, 7½ feet at the top, its height being 11 feet. All the trees have large spreading roots, solid and strong, sometimes branching, and traced to a distance of several feet, and presumed to extend much farther. Mr. Hawkshaw, who has described these fossils, thinks that, although they were hollow when submerged, they may have consisted originally of hard wood throughout; for solid dicotyledonous trees, when prostrated in tropical forests, as in Venezuela, on the shore of the Caribbean Sea, were observed by him to be destroyed in the interior, so that little more is left than an outer shell, consisting chiefly of the bark. This decay, he says, goes on

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* Quart. Geol. Journ., vol. v., Mem., p. 17.

† Anniv. Address to Geol. Soc., 1840.

most rapidly in low and flat tracts, in which there is a deep rich soil and excessive moisture, supporting tall forest-trees and large palms, below which bamboos, canes, and minor palms flourish luxuriantly. Such tracts, from their lowness, would be most easily submerged, and their dense vegetation might then give rise to a seam of coal.*

In a deep valley near Capel-Coelbren, branching from the higher part of the Swansea valley, four stems of upright *Sigillariæ* were seen in 1838, piercing through the coal-measures of S. Wales; one of them was 2 feet in diameter, and one 13 feet and a half high, and they were all found to terminate downwards in a bed of coal. "They appear," says Sir H. De la Beche, "to have constituted a portion of a subterranean forest at the epoch when the lower carboniferous strata were formed." †

In a colliery near Newcastle, say the authors of the Fossil Flora, a great number of *Sigillariæ* were placed in the rock as if they had retained the position in which they grew. Not less than thirty, some of them 4 or 5 feet in diameter, were visible within an area of 50 yards square, the interior being sandstone, and the bark having been converted into coal. The roots of one individual were found imbedded in shale; and the trunk, after maintaining a perpendicular course and circular form for the height of about 10 feet, was then bent over so as to become horizontal. Here it was distended laterally, and flattened so as to be only one inch thick, the flutings being comparatively distinct.‡ Such vertical stems are familiar to our miners, under the name of coal-pipes. One of them, 72 feet in length, was discovered, in 1829, near Gosforth, about five miles from Newcastle, in coal-grit, the strata of which it penetrated. The exterior of the trunk was marked at intervals with knots, indicating the points at which branches had shot off. The wood of the interior had been converted into carbonate of lime; and its structure was beautifully shown by cutting transverse slices, so thin as to be transparent. (See p. 40.)

These "coal-pipes" are much dreaded by our miners, for almost every year in the Bristol, Newcastle, and other coal-fields, they are the cause of fatal accidents. Each cylindrical cast of a tree, formed of solid sandstone, and increasing gradually in size towards the base, and being without branches, has its whole weight thrown downwards, and receives no support from the coating of friable coal which has replaced the bark. As soon, therefore, as the cohesion of this external layer is overcome, the heavy column falls suddenly in a perpendicular or oblique direction from the roof of the gallery whence coal has been extracted, wounding or killing the workman who stands below. It is strange to reflect how many thousands of these trees fell originally in their native forests in obedience to the law of gravity; and how the few which continued to stand erect, obeying,

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* Hawkshaw, Geol. Trans., Second Series, vol. vi. pp. 173. 177., pl. 17.

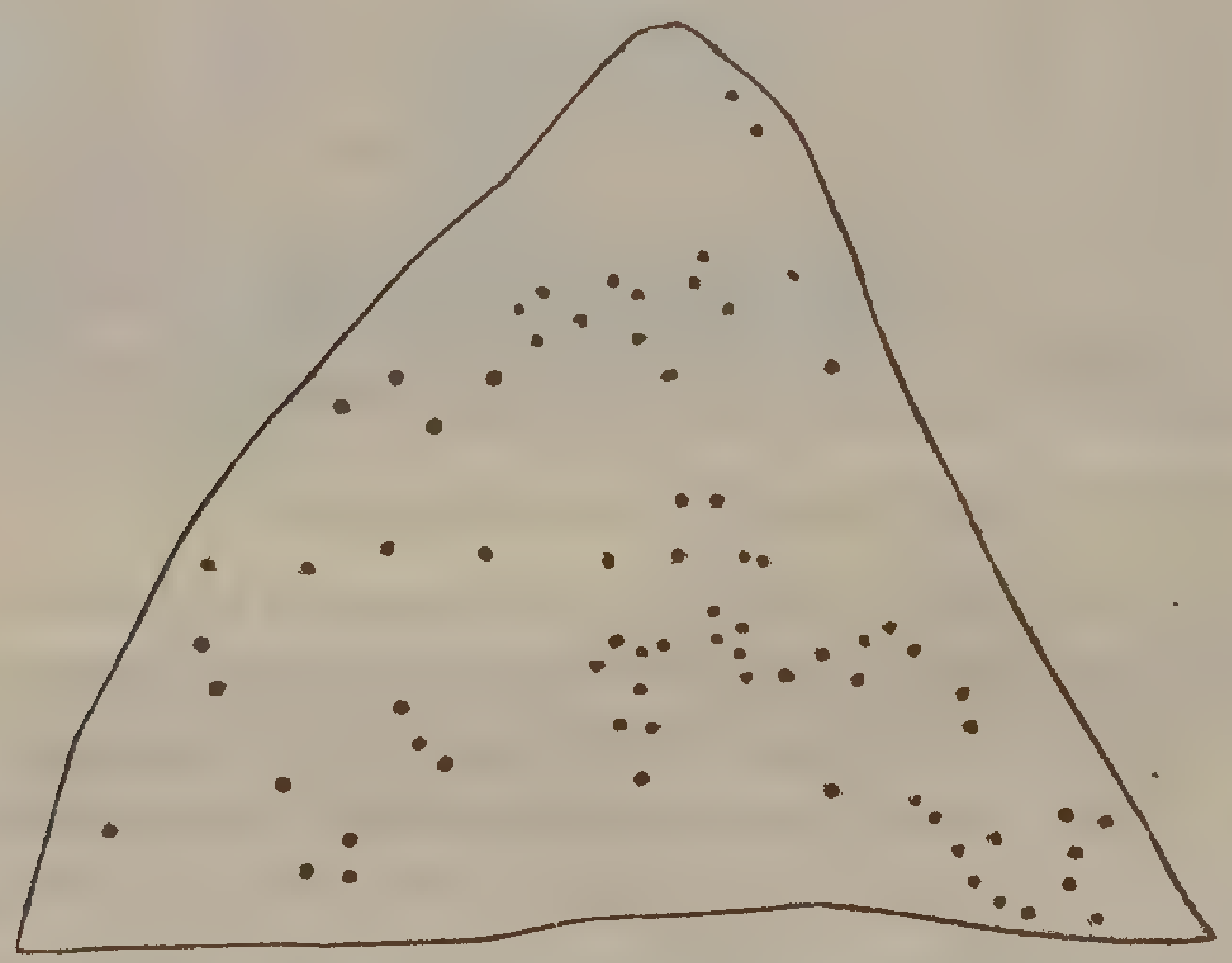
† Geol. Report on Cornwall, Devon, and Somerset, p. 143.

‡ Lindley and Hutton, Foss. Flo. part 6. p. 150.

after myriads of ages, the same force, are cast down to immolate their human victims.

It has been remarked, that if, instead of working in the dark, the miner was accustomed to remove the upper covering of rock from each seam of coal, and to expose to the day the soils on which ancient forests grew, the evidence of their former growth would be obvious. Thus in South Staffordshire a seam of coal was laid bare in the year 1844, in what is called an open work at Parkfield Colliery, near Wolverhampton. In the space of about a quarter of an acre the stumps of no less than 73 trees with their roots attached appeared, as shown in the annexed plan (fig. 489.), some of them more than 8 feet in circumference. The trunks, broken off close to the root, were lying prostrate in every direction, often crossing each other. One of them measured 15, another 30 feet in length, and others less. They were invariably flattened to the thickness of one or two inches, and converted into coal. Their roots formed part of a stratum of coal 10 inches thick, which rested on a layer of clay 2 inches thick, below which was a second forest, resting on a 2-foot seam of coal. Five feet below this again was a third forest with large stumps of *Lepidodendra*, *Calamites*, and other trees.

Fig. 489.



Ground-plan of a fossil forest, Parkfield Colliery, near Wolverhampton, showing the position of 73 trees in a quarter of an acre.*

In the account given, in 1821, by M. Alex. Brongniart† of the coal-mine of Treuil, at St. Etienne, near Lyons, he states, that distinct horizontal strata of micaceous sandstone are traversed by vertical trunks of monocotyledonous vegetables, resembling bamboos or large *Equiseta* (fig. 490.). Since the consolidation of the stone, there has been here and there a sliding movement, which has broken the continuity of the stems, throwing the upper parts of them on one side, so that they are often not continuous with the lower.

From these appearances it was inferred that we have here the

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* Messrs. Beckett and Ick. Proceed. Geol. Soc., vol. iv. p. 287.

† Annales des Mines, 1821.

Fig. 490.

Section showing the erect position of fossil trees in coal-sandstone at St. Etienne. (Alex. Brongniart.)

monuments of a submerged forest. I formerly objected to this conclusion, suggesting that, in that case, all the roots ought to have been found at one and the same level, and not scattered irregularly through the mass. I also imagined that the soil to which the roots were attached should have been different from the sandstone in which the trunks are enclosed. Having, however, seen calamites near Pictou, in Nova Scotia, buried at various heights in sandstone and in similar erect attitudes, I have now little doubt that M. Brongniart's view was correct. These plants seem to have grown on a sandy soil, liable to be flooded from time to time, and raised by new accessions of sediment, as may happen in swamps near the banks of a large river in its delta. Trees which delight in marshy grounds are not injured by being buried several feet deep at their base; and other trees are continually rising up from new soils, several feet above the level of the original foundation of the morass. In the banks of the Mississippi, when the water has fallen, I have seen sections of a similar deposit in which portions of the stumps of trees with their roots *in situ* appeared at many different heights.*

When I visited, in 1843, the quarries of Treuil above-mentioned, the fossil trees seen in fig. 490. were removed, but I obtained proofs of other forests of erect trees in the same coal-field.

Snags. — In 1830, a slanting trunk was exposed in Craigleith quarry, near Edinburgh, the total length of which exceeded 60 feet. Its diameter at the top was about 7 inches, and near the base it measured 5 feet in its greater, and 2 feet in its lesser width. The bark was converted into a thin coating of the purest and finest coal, forming a striking contrast in colour with the white quartzose sandstone

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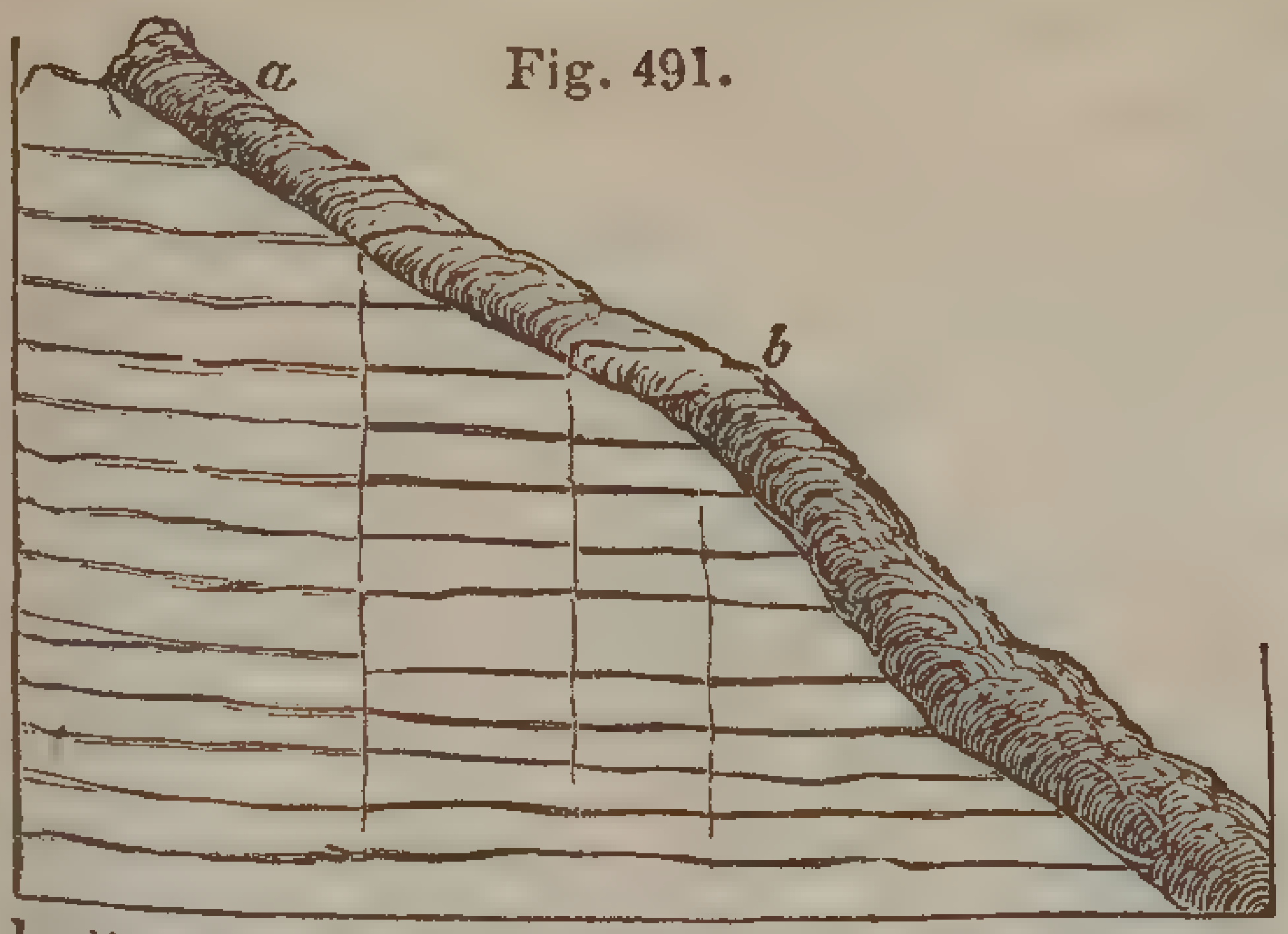
* Principles of Geol., 9th ed., p. 268.

Fig. 491.



Inclined position of a fossil tree, cutting through horizontal beds of sandstone, Craigleith quarry, Edinburgh. Angle of inclination from *a* to *b* 27°.

in which it lay. The annexed figure represents a portion of this tree, about 15 feet long, which I saw exposed in 1830, when all the strata had been removed from one side. The beds which remained were so unaltered and undisturbed at the point of junction, as clearly to show that they had been tranquilly deposited round the tree, and that the tree had not subsequently pierced through them, while they were yet in a soft state. They were composed chiefly of siliceous sandstone, for the most part white; and divided into laminæ so thin, that from six to fourteen of them might be reckoned in the thickness of an inch. Some of these thin layers were dark, and contained coaly matter; but the lowest of the intersected beds were calcareous. The tree could not have been hollow when imbedded, for the interior still preserved the woody texture in a perfect state, the petrifying matter being, for the most part, calcareous.* It is also clear that the lapidifying matter was not introduced laterally from the strata through which the fossil passes, as most of these were not calcareous. It is well known that, in the Mississippi and other great American rivers, where thousands of trees float annually down the stream, some sink with their roots downwards, and become fixed in the mud. Thus placed, they have been compared to a lance in rest; and so often do they pierce through the bows of vessels which run against them, that they render the navigation extremely dangerous. Mr. Hugh Miller mentions four other huge trunks exposed in quarries near Edinburgh, which lay diagonally across the strata at an angle of about 30°, with their lower or heavier portions downwards, the roots of all, save one, rubbed off by attrition. One of these was 60 and another 70 feet in length, and from 4 to 6 feet in diameter.

The number of years for which the trunks of trees, when constantly submerged, can resist decomposition, is very great; as we might suppose from the durability of wood, in artificial piles, permanently covered by water. Hence these fossil snags may not imply a rapid accumulation of beds of sand, although the channel of a river or part of a lagoon is often filled up in a very few years.

Nova Scotia.—One of the finest examples in the world of a succession of fossil forests of the carboniferous period, laid open to view in a natural section, is that seen in the lofty cliffs called the South Joggins, bordering the Chignecto Channel, a branch of the Bay of Fundy, in Nova Scotia.†

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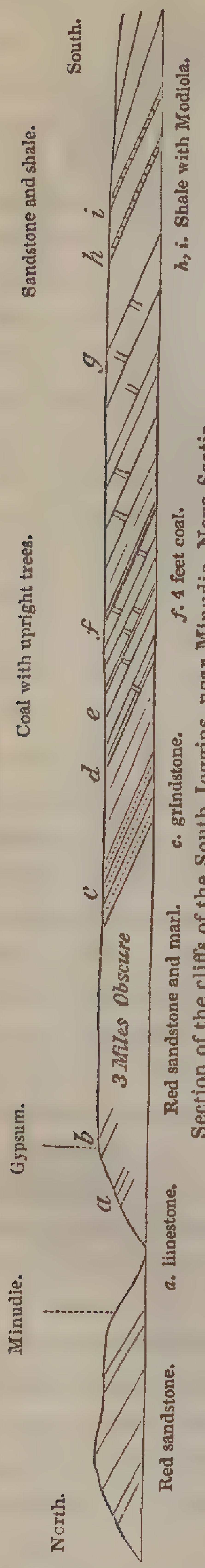
* See figures of texture, Witham, Foss. Veget., pl. 3.

† See Lyell's Travels in N. America, vol. ii. p. 179.; and Dawson, Geol. Journ. No. 37.

Fig. 492.



Section of the cliffs of the South Joggins, near Minudie, Nova Scotia.

In the annexed section (fig. 492.), which I examined in July, 1842, the beds from *c* to *i* are seen all dipping the same way, their average inclination being at an angle of 24° S.S.W. The vertical height of the cliffs is from 150 to 200 feet; and between *d* and *g*, in which space I observed seventeen trees in an upright position, or, to speak more correctly, at right angles to the planes of stratification, I counted nineteen seams of coal, varying in thickness from 2 inches to 4 feet. At low tide a fine horizontal section of the same beds is exposed to view on the beach. The thickness of the beds alluded to, between *d* and *g*, is about 2,500 feet, the erect trees consisting chiefly of large *Sigillariæ*, occurring at ten distinct levels, one above the other; but Mr. Logan, who afterwards made a more detailed survey of the same line of cliffs, found erect trees at seventeen levels, extending through a vertical thickness of 4,515 feet of strata; and he estimated the total thickness of the carboniferous formation, with and without coal, at no less than 14,570 feet, every where devoid of marine organic remains.* The usual height of the buried trees seen by me was from 6 to 8 feet; but one trunk was about 25 feet high and 4 feet in diameter, with a considerable bulge at the base. In no instance could I detect any trunk intersecting a layer of coal, however thin; and most of the trees terminated downwards in seams of coal. Some few only were based in clay and shale; none of them, except calamites, in sandstone. The erect trees, therefore, appeared in general to have grown on beds of coal. In the underclays *Stigmaria* abounds.

In 1852 Mr. Dawson and the author made a detailed examination of one portion of the strata, 1400 feet thick, where the coal-seams are most frequent, and found evidence of root-bearing soils at sixty-eight different levels. Like the seams of coal which often cover them, these root-beds or old soils are at present the most destructible masses in the whole cliff, the sandstones and laminated shales being harder and more capable of resisting the action of the waves and the weather. Originally the reverse was doubtless true, for in the existing delta of the Mississippi those clays in which the innumerable roots of the deciduous cypress and other swamp trees ramify in all directions are seen to withstand far more effectually the undermining power of the

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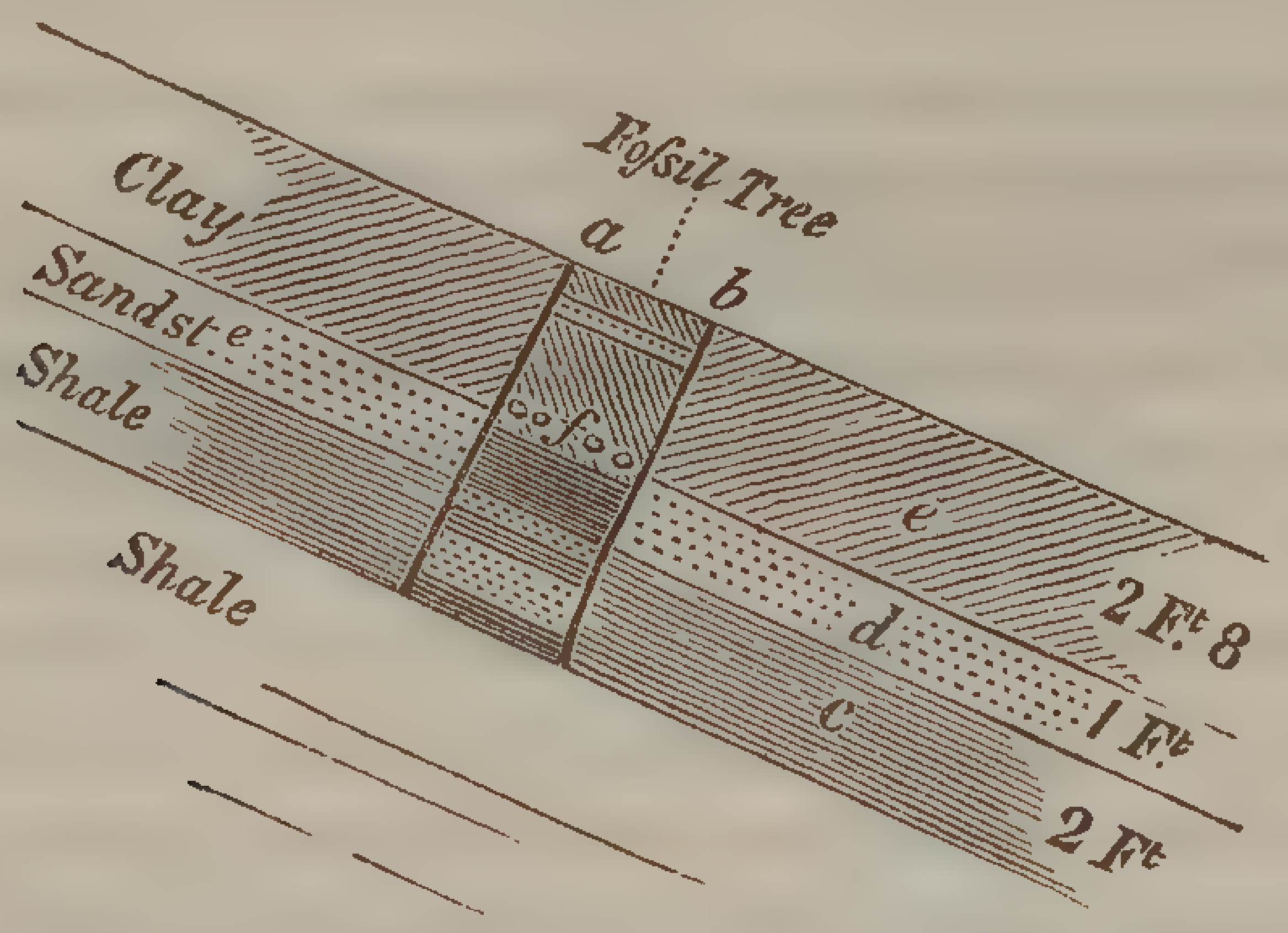
* Quart. Geol. Journ., vol. ii. p. 177.

river, or of the sea at the base of the delta, than do beds of loose sand or layers of mud not supporting trees.

This fact may explain why seams of coal have so often escaped denudation, and remain continuous over wide areas, since the tough roots, now turned to coal, which once traversed them, would enable them to resist a current of water, whilst other members of the coal-formation, in their original and unconsolidated state of sand and mud, would be readily removed.

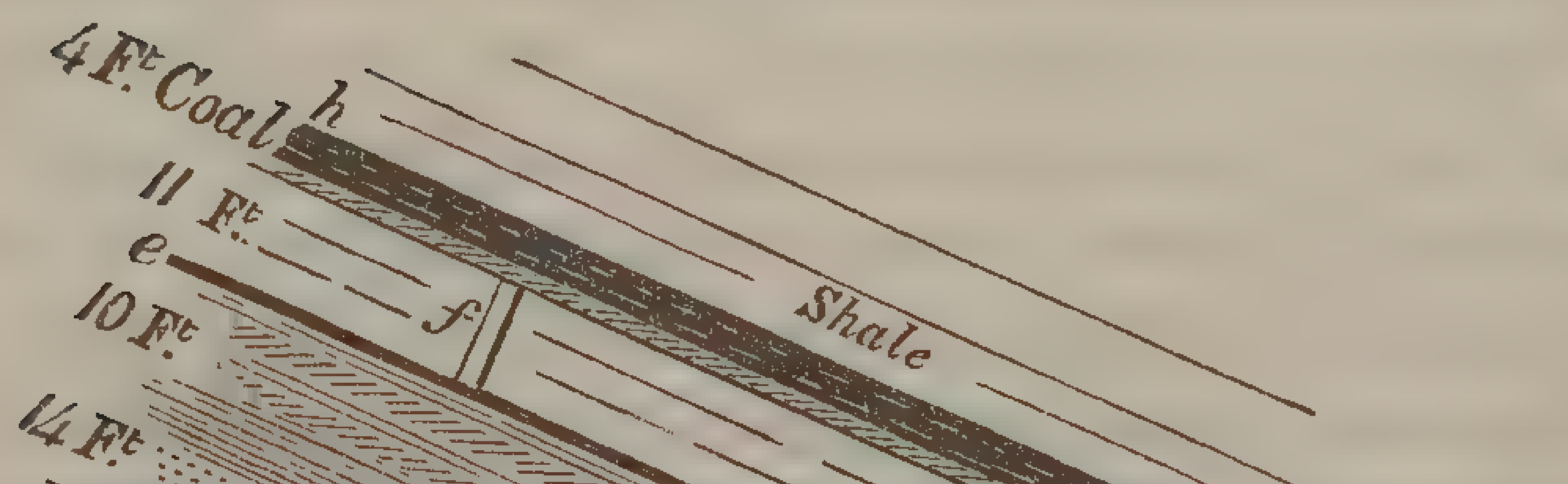
In regard to the plants, they belonged to the same genera, and most of them to the same species, as those met with in the distant coal-fields of Europe. In the sandstone, which filled their interiors, I frequently observed fern leaves, and sometimes fragments of *Stigmaria*, which had evidently entered together with sediment after the trunk had decayed and become hollow, and while it was still standing under water. Thus the tree, *a b*, fig. 493., the same which is represented at *a*, fig. 494., or in the bed *e* in the larger section, fig. 492., is a hollow trunk 5 feet 8 inches in length, traversing various strata, and cut off at the top by a layer of clay 2 feet thick, on which rests a seam of coal (*b*, fig. 494.) 1 foot thick. On this coal again stood two large trees (*c* and *d*), while at a greater height the trees *f* and *g* rest upon a thin seam of coal (*e*), and above them is an underclay, supporting the 4-foot coal.

Fig. 493.



Fossil tree at right angles to the planes of stratification.
Coal-measures, Nova Scotia.

Fig. 494.



Erect fossil trees. Coal-measures, Nova Scotia.

If we now return to the tree first mentioned (fig. 493.), we find the diameter (*a b*) 14 inches at the top and 16 inches at the bottom, the length of the trunk 5 feet 8 inches. The strata in the interior consisted of a series entirely different from those on the outside. The lowest of the three outer beds which it traversed consisted of purplish and blue shale (*c*, fig. 493.), 2 feet thick, above which was sandstone (*d*) 1 foot thick, and, above this, clay (*e*) 2 feet 8 inches. But, in the interior, were nine distinct layers of different composition: at the bottom, first, shale 4 inches, then sandstone 1 foot, then shale 4 inches, then sandstone 4 inches, then shale 11 inches, then clay (*f*) with nodules of ironstone 2 inches, then pure clay 2 feet, then sandstone 3 inches, and, lastly, clay 4 inches. Owing to the outward slope of the face of the cliff, the section (fig. 493.) was not exactly perpendicular to the axis of the tree; and hence, probably, the apparent sudden termination at the base without a stump and roots.

In this example the layers of matter in the inside of the tree are more numerous than those without; but it is more common in the coal-measures of all countries to find a cylinder of pure sandstone,—the cast of the interior of a tree,—intersecting a great many alternating beds of shale and sandstone, which originally enveloped the trunk as it stood erect in the water. Such a want of correspondence in the materials outside and inside, is just what we might expect if we reflect on the difference of time at which the deposition of sediment will take place in the two cases; the imbedding of the tree having gone on for many years before its decay had made much progress.

In many places distinct proof is seen that the enveloping strata took years to accumulate, for some of the sandstones surrounding erect sigillarian trunks support at different levels roots and stems of *Calamites;* the *Calamites* having begun to grow after the older *Sigillariæ* had been partially buried.

The general absence of structure in the interior of the large fossil trees of the Coal implies the very durable nature of their bark, as compared with their woody portion. The same difference of durability of bark and wood exists in modern trees, and was first pointed out to me by Mr. Dawson, in the forests of Nova Scotia, where the Canoe Birch (*Betula papyracea*) has such tough bark that it may sometimes be seen in the swamps looking externally sound and fresh, although consisting simply of a hollow cylinder with all the wood decayed and gone. In such cases the submerged portion is sometimes found filled with mud.

One of the erect fossil trees of the South Joggins has been shown by Mr. Dawson to have Araucarian structure, so that some *Coniferæ* of the Coal Period grew in the same swamps as *Sigillariæ*, just as now the deciduous Cypress (*Taxodium distichum*) abounds in the marshes of Louisiana even to the edge of the sea.

When the carboniferous forests sank below high-water mark a species of *Spirorbis* or *Serpula* (fig. 498.) attached itself to the outside of the stumps and stems of the erect trees, adhering occasionally even to the interior of the bark,—another proof that the process of envelopment was very gradual. These hollow upright trees, covered with innumerable marine annelids, reminded me of a "cane-brake," as it is commonly called, consisting of tall reeds of *Arundinaria macrosperma*, which I saw, in 1846, at the Balize, or extremity of the delta of the Mississippi. Although these reeds are freshwater plants, they were covered with barnacles, having been killed by an incursion of salt water over an extent of many acres, where the sea had for a season usurped a space previously gained from it by the river. Yet the dead reeds, in spite of this change, remained standing in the soft mud, showing how easily the *Sigillariæ*, hollow as they were but supported by strong roots, may have resisted an incursion of the sea.

The high tides of the Bay of Fundy, rising more than 60 feet, are so destructive as to undermine and sweep away continually the whole face of the cliffs, and thus a new crop of erect fossil trees is brought into view every three or four years. They are known to extend over a space between two or three miles from north to south, and more than twice that distance from east to west, being seen in the banks of streams intersecting the coal-field.

In Cape Breton, Mr. Richard Brown has observed in the Sydney coal-field a total thickness of coal-measures, without including the underlying millstone-grit, of 1843 feet, dipping at an angle of 8°. He has published minute details of the whole series, showing at how many different levels erect trees occur, consisting of *Sigillaria, Lepidodendron, Calamites*, and other genera. In one place eight erect trunks, with roots and rootlets attached to them, were seen at the same level, within a horizontal space 80 feet in length. Beds of coal of various thickness are interstratified. Taking into account forty-one clays filled with roots of *Stigmaria* in their natural position, and eighteen layers of upright trees at other levels, there is, on the whole, clear evidence of at least fifty-nine fossil forests, ranged one above the other, in this coal-field, in the above-mentioned thickness of strata.*

The fossil shells of Cape Breton and those of the Nova Scotia section (p. 380.), consisting of *Cypris*, *Unio* (?), *Modiola*, and an annelid probably of the genus *Spirorbis* (see *fig.* 498.), seem to indicate brackish water; but we ought never to be surprised if, in pursuing the same stratum, we should come either to a freshwater or a purely marine deposit; for this will depend upon our taking a direction higher up or lower down the ancient river or delta deposit.

In the strata above described, the association of clays supporting upright trees, with other beds containing marine and brackish-water shells, implies such a repeated change in the same area, from land to sea and from sea to land, that here, if anywhere, we should expect to meet with evidence of the fall of rain on ancient sea-beaches. Accordingly rain-prints were seen by me and Mr. Dawson at various

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* Geol. Quart. Journ., vol. ii. p. 393.; and vol. vi. p. 115.

levels, but the most perfect hitherto observed were discovered by Mr. Brown near Sydney in Cape Breton. They consist of very delicate impressions of rain-drops on greenish slates, with several worm-tracks (*a*, *b*, fig. 495.), such as usually accompany rain-marks on the recent mud of the Bay of Fundy, and other modern beaches.

Fig. 495. Fig. 496.

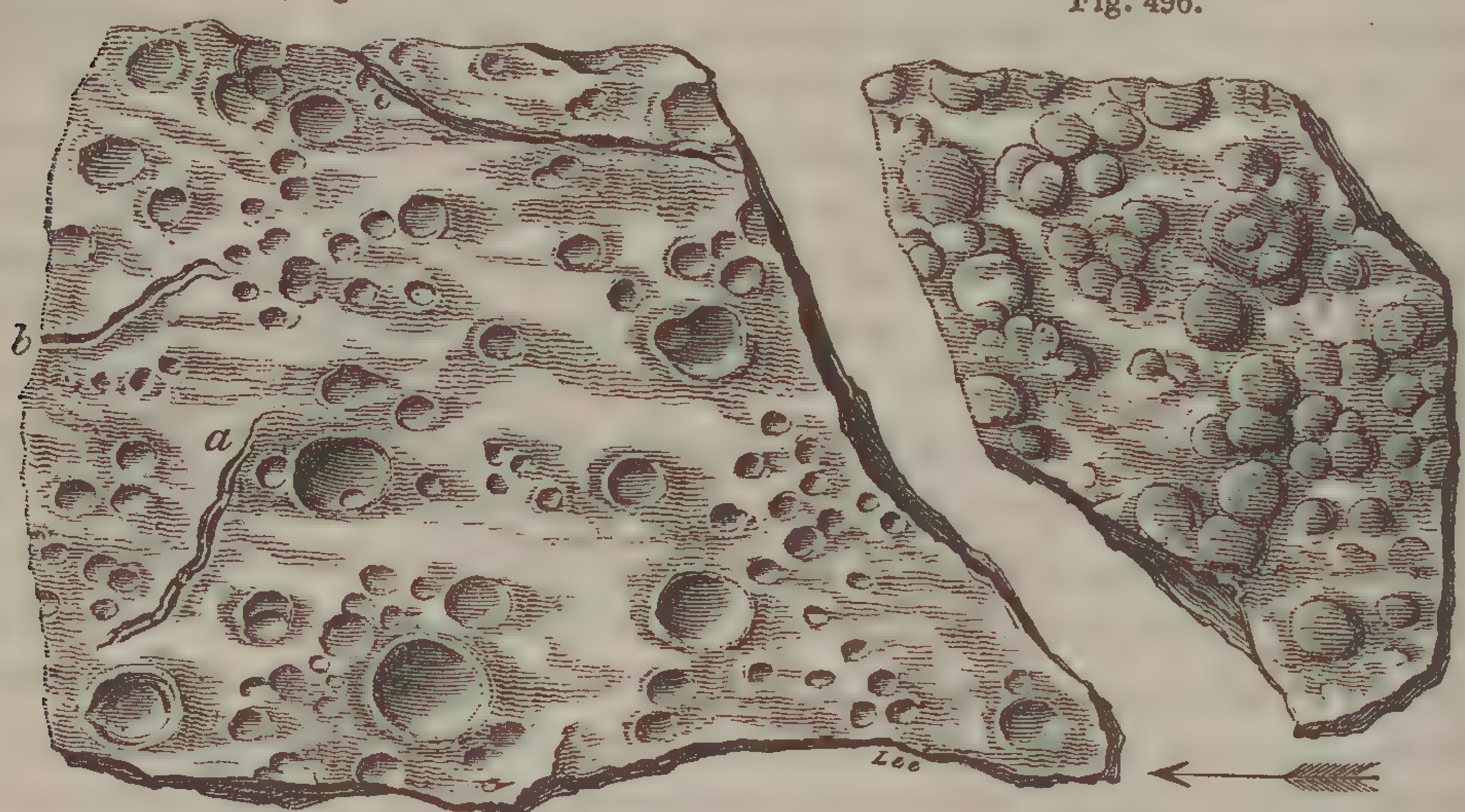

Fig. 495. Carboniferous rain-prints with worm-tracks (*a*, *b*) on green shale, from Cape Breton, Nova Scotia. *Natural size.*

Fig. 496. Casts of rain-prints on a portion of the same slab, fig. 495., seen on the under side of an incumbent layer of arenaceous shale. *Natural size.*

The arrow represents the supposed direction of the shower.

The casts of rain-prints, in figs. 496. and 497., project from the under side of two layers, occurring at different levels, the one a sandy shale, resting on the green shale (fig. 495.), the other a sandstone presenting a similar warty or blistered surface, on which are also observable some small ridges as at *a*, which stand out in relief, and afford evidence of cracks formed by the shrinkage of subjacent clay, on which rain had fallen. Many of the associated sandstones are ripple-marked.

Fig. 497.

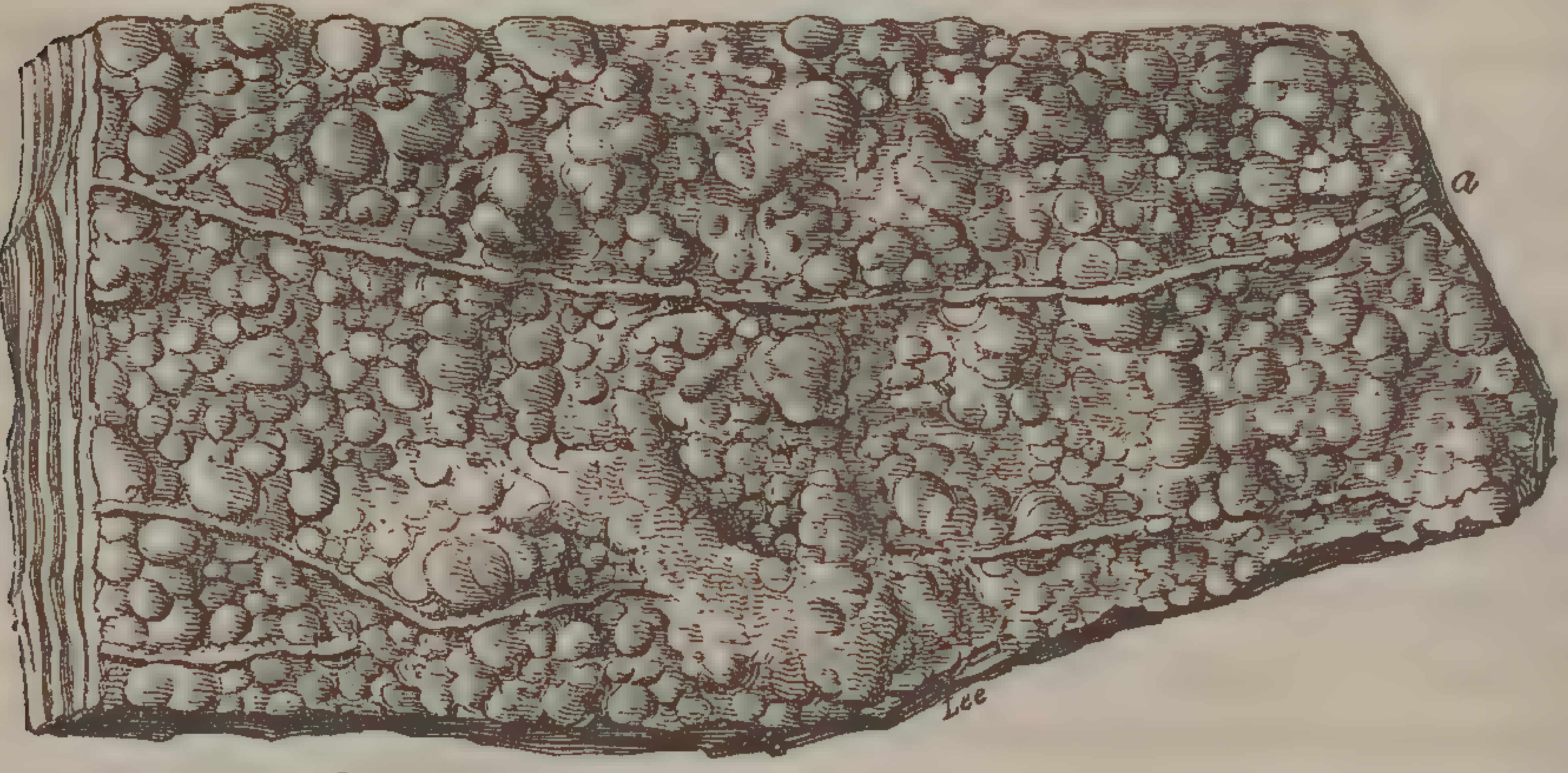

Fig. 497. Casts of carboniferous rain-prints and shrinkage-cracks (*a*) on the under side of a layer of sandstone, Cape Breton, Nova Scotia. *Natural size.*

The great humidity of the climate of the coal-period had been previously inferred from the nature of its vegetation and the continuity of its forests for hundreds of miles; but it is satisfactory to have at length obtained such positive proofs of showers of rain, the drops of which resembled in their average size those which now fall from the clouds. From such data we may presume that the atmosphere of the carboniferous period corresponded in density with that now investing the globe, and that different currents of air varied then as now in temperature, so as to give rise, by their mixture, to the condensation of aqueous vapour.

The more closely the strata productive of coal have been studied the greater has become the force of the evidence in favour of their having originated in the manner of modern deltas. They display a vast thickness of stratified mud and fine sand without pebbles, and in them are seen countless stems, leaves, and roots of terrestrial plants, free for the most part from all intermixture of marine remains,—circumstances which imply the persistency in the same region of a vast body of fresh water. This water was also charged, like that of a great river, with an inexhaustible supply of sediment, which seems to have been transported over alluvial plains so far from the higher grounds that all coarser particles and gravel were left behind. Such phenomena imply the drainage and denudation of a continent or large island, having within it one or more ranges of mountains. The partial intercalation of brackish-water beds at certain points is equally consistent with the theory of a delta, the lower parts of which are always exposed to be everflowed by the sea even where no oscillations of level are experienced.

The purity of the coal itself, or the absence in it of earthy particles and sand, throughout areas of vast extent, is a fact which appears very difficult to explain when we attribute each coal-seam to a vegetation growing in swamps. It has been asked how, during river inundations, capable of sweeping away the leaves of ferns and the stems and roots of *Sigillariæ* and other trees, could the waters fail to transport some fine mud into the swamps? One generation after another of tall trees grew with their roots in mud, and their leaves and prostrate trunks formed layers of vegetable matter, which was afterwards covered with mud since turned to shale. Yet the coal itself or altered vegetable matter remained all the while unsoiled by earthy particles. This enigma, however perplexing at first sight, may, I think, be solved, by attending to what is now taking place in deltas. The dense growth of reeds and herbage which encompasses the margins of forest-covered swamps in the valley and delta of the Mississippi is such that the fluviatile waters, in passing through them, are filtered and made to clear themselves entirely before they reach the areas in which vegetable matter may accumulate for centuries, forming coal if the climate be favourable. There is no possibility of the least intermixture of earthy matter in such cases. Thus in the large submerged tract called the "Sunk Country," near New Madrid, forming part of the western side of the valley of the Mississippi, erect trees have been standing ever since the year 1811-12, killed by the great earthquake of that date; lacustrine and swamp plants have been growing there in the shallows, and several rivers have annually inundated the whole space, and yet have been unable to carry in any sediment within the outer boundaries of the morass, so dense is the marginal belt of reeds and brushwood. It may be affirmed that generally in the "cypress swamps" of the Mississippi no sediment mingles with the vegetable matter accumulated there from the decay of trees and semi-aquatic plants. As a singular proof of this fact, I may mention that whenever any part of a swamp in Louisiana is dried up, during an unusually hot season, and the wood set on fire, pits are burnt into the ground many feet deep, or as far down as the fire can descend, without meeting with water, and it is then found that scarcely any residuum or earthy matter is left.* At the bottom of all these "cypress swamps" a bed of clay is found, with roots of the tall cypress (*Taxodium distichum*), just as the underclays of the coal are filled with *Stigmaria.*

It has been already stated, that the carboniferous strata at the South Joggins, in Nova Scotia, are nearly three miles thick, and the coal-measures are ascertained to be of vast thickness near Pictou, more than 100 miles to the eastward. If, therefore, we speculate on the probable volume of solid matter, contained in the Nova Scotia coal-fields, there appears little danger of erring on the side of excess if we take the average thickness of the beds at 7,500 feet, or about half that ascertained to exist in one carefully measured section. As to the area of the coal-field, it includes a large part of New Brunswick to the west, and extends north to Prince Edward's Island, and probably to the Magdalen Isles. When we add the Cape Breton beds, and the connecting strata, which must have been denuded or are still concealed beneath the waters of the Gulf of St. Lawrence, we obtain an area comprising about 36,000 square miles. This, with the thickness of 7,500 feet before assumed, will give 51,000 cubic miles of solid matter as the volume of the carboniferous rocks.

The Mississippi would take more than two million of years to convey to the Gulf of Mexico an equal quantity of solid matter in the shape of sediment, assuming the average discharge of water, in that great river to be, as calculated by Mr. Forshey, 450,000 cubic feet per second, throughout the year, and the total quantity of mud to be, as estimated by Mr. Riddell, 3,702,758,400 cubic feet in the year.†

The Ganges, according to the data supplied to me by Mr. Everest and Captain Strachey, conveys so much larger a volume of solid matter annually to the Bay of Bengal, that it might accomplish a similar task in 375,000 years, or in less than a fifth of the time which the Mississippi would require.‡

As the lowest of the carboniferous strata of Nova Scotia, like the middle and uppermost, consist of shallow-water beds, the whole vertical subsidence of three miles, at the South Joggins, must have

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* Lyell's Second Visit to the U. S., vol. ii. p. 245.; and American Journ. of Science, 2d series, vol. v. p. 17.

† Principles of Geology, 9th ed. 1853, p. 273.

‡ Ibid. 1853, p. 283.

taken place gradually. If then this depression was brought about in the course of 375,000 years, it did not exceed the rate of four feet in a century, resembling that now experienced in certain countries, where, whether the movement be upward or downward, it is quite insensible to the inhabitants, and only known by scientific inquiry. If, on the other hand, it was brought about in two millions of years according to the other standard before alluded to, the rate would be only six inches in a century. But the same movement taking place in an upward direction would be sufficient to uplift a portion of the earth's crust to the height of Mont Blanc, or to a vertical elevation of three miles above the level of the sea.

The delta of the Ganges presents in one respect a striking parallel to the Nova Scotia coal-field, since at Calcutta at the depth of eight or ten feet from the surface the buried stools of trees with their roots attached have been found in digging tanks, indicating an ancient soil now underground; and, in boring on the same site for an Artesian well to the depth of 481 feet, other signs of ancient forest-covered lands and peaty soils have been observed at several depths, even as far down as 300 feet and more below the level of the sea. As the strata pierced through contained freshwater remains of recent species of plants and animals, they imply a subsidence which has been going on contemporaneously with the accumulation of fluviatile mud.

In the English coal-fields the same association of fresh, or rather brackish-water strata, with marine, in close connection with beds of coal of terrestrial origin, has been frequently recognised. Thus, for example, a deposit near Shrewsbury, probably formed in brackish water, has been described by Sir R. Murchison as the youngest member of the carboniferous series of that district, at the point where the coal-measures are in contact with the Permian or "Lower New Red." It consists of shales and sandstones about 150 feet thick, with coal and traces of plants; including a bed of limestone, varying from 2 to 9 feet in thickness, which is cellular, and resembles some lacustrine limestones of France and Germany. It has been traced for 30 miles in a straight line, and can be recognised at still more distant points. The characteristic fossils are a small bivalve, having the form of a *Cyclas* or *Cyrena*, also a small entomostracan which may be a *Cypris* or, if marine, a *Cythere* (fig. 499.), and the microscopic shell of an annelid of an extinct genus called *Microconchus* (fig. 498.), allied to *Serpula* or *Spirorbis*.

Fig. 498.

a. *Microconchus* (*Spirorbis*) *carbonarius*. Nat. size, and magnified.
b. var. of same.

Fig. 499.

Cypris? inflata (or *Cythere?*). Nat. size, and magnified. Murchison.*

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* Silurian System, p. 84.

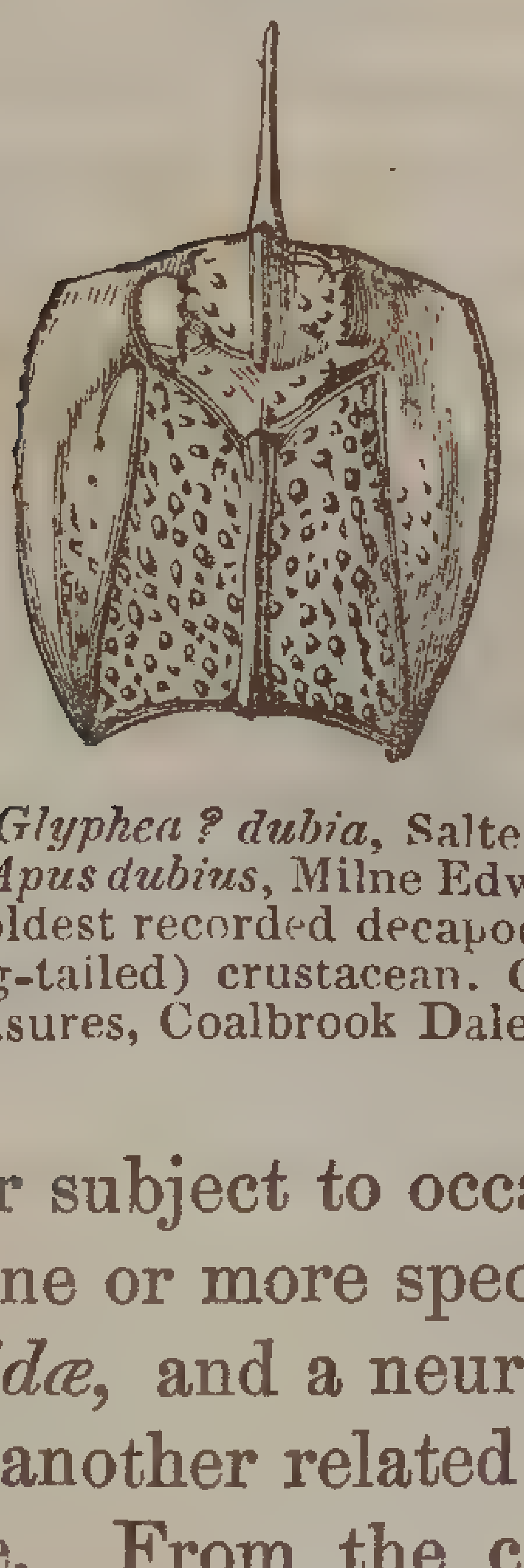
In the lower coal-measures of Coalbrook Dale, the strata, according to Mr. Prestwich, often change completely within very short distances, beds of sandstone passing horizontally into clay, and clay into sandstone. The coal-seams often wedge out or disappear; and sections, at places nearly contiguous, present marked lithological distinctions. In this single field, in which the strata are from 700 to 800 feet thick, between forty and fifty species of terrestrial plants have been discovered, besides several fishes of the genera *Megalichthys*, *Holoptychius*, and others. *Crustacea* also are met with, of the genus *Limulus* (see fig. 500.), resembling in all essential characters the *Limuli* of the Oolitic period, and the king-crab of the modern seas. They were smaller, however, than the living form, and had the abdomen deeply grooved across, and serrated at its edges. In this specimen, the tail is wanting; but in another, of a second species, from Coalbrook Dale, the tail is seen to agree with that of the living Limulus.

Fig. 500.

Limulus rotundatus, Prestwich. Coal, Coalbrook Dale.

The perfect carapace of a long-tailed or decapod crustacean has also been found in the ironstone of these strata by Mr. Ick (see fig. 501.). It is referred by Mr. Salter to *Glyphea*, a genus also occurring in the Lias and Oolite. There are also upwards of forty species of mollusca, among which are two or three referred to the freshwater genus *Unio*, and others of marine forms, such as *Nautilus*, *Orthoceras*, *Spirifer*, and *Productus*. Mr. Prestwich suggests that the intermixture of beds containing freshwater shells with others full of marine remains, and the alternation of coarse sandstone and conglomerate with beds of fine clay or shale containing the remains of plants, may be explained by supposing the deposit of Coalbrook Dale to have originated in a bay of the sea or estuary into which flowed a considerable river subject to occasional freshes.*

Fig. 501.



Glyphea ? dubia, Salter. Syn. *Apus dubius*, Milne Edwards. The oldest recorded decapod (or long-tailed) crustacean. Coal-measures, Coalbrook Dale.

One or more species of scorpions, two beetles of the family *Curculionidæ*, and a neuropterous insect resembling the genus *Corydalis*, and another related to the *Phasmidæ*, have been found at Coalbrook Dale. From the coal of Wetting in Westphalia several specimens of the cockroach or *Blatta* family, and the wing of a cricket (*Acridites*), have been described by Germar.†

More recently (1854) Mr. Fr. Goldenberg has published descriptions of no less than twelve species of insects from the nodular

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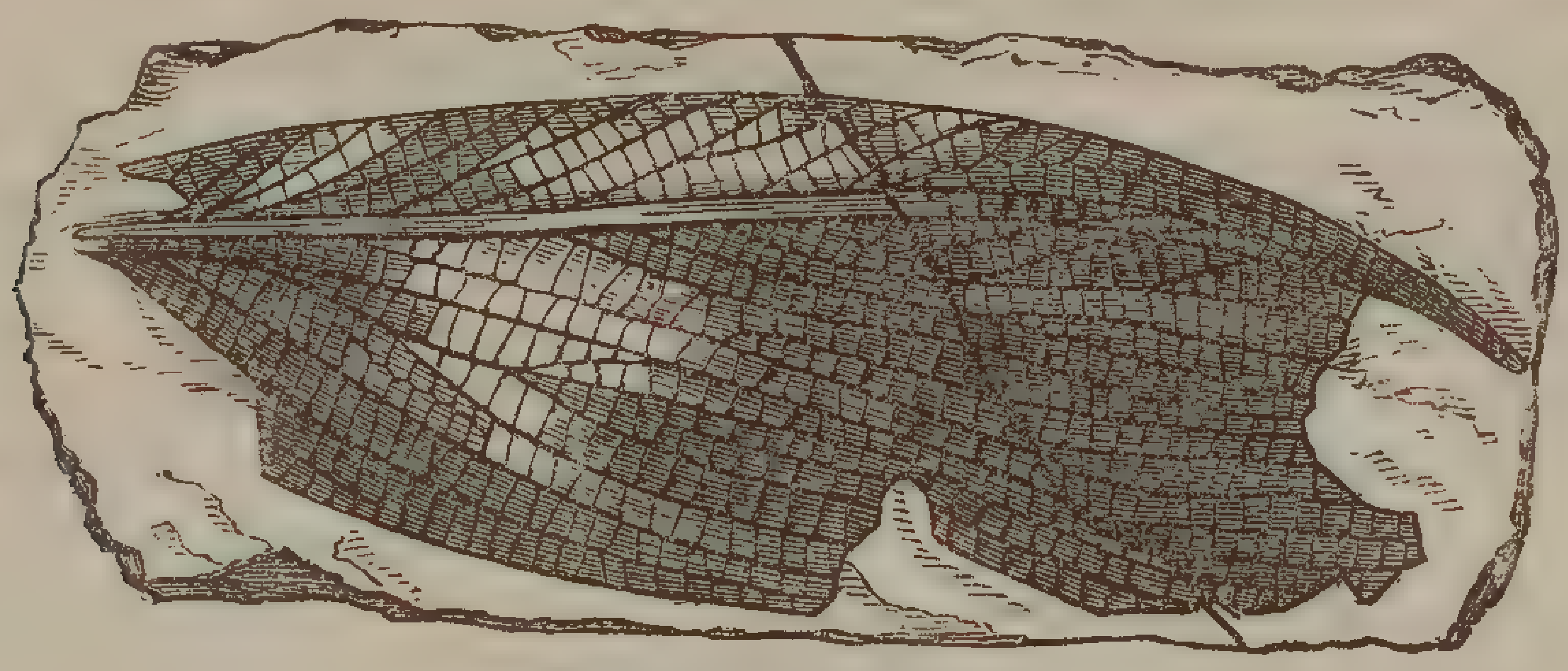
* Prestwich, Geol. Trans., 2d series, vol. v. p. 440.

† See Münster's Beitr. vol. v. pl. 13. 1842.

clay-iron-stone of Saarbrück near Treves.* They are associated with the leaves and branches of fossil ferns. Among them are several *Blattinæ*, three species of *Neuroptera*, one beetle of the *Scarabæus* family, a grasshopper or locust, *Gryllacris* (see fig. 502.), and several white ants or *Termites.* These newly added species probably outnumber all we knew before of the fossil insects of the coal.

Fig. 502.



Wing of a Grasshopper.
Gryllacris lithanthraca, Goldenberg.
Coal, Saarbrück near Treves.

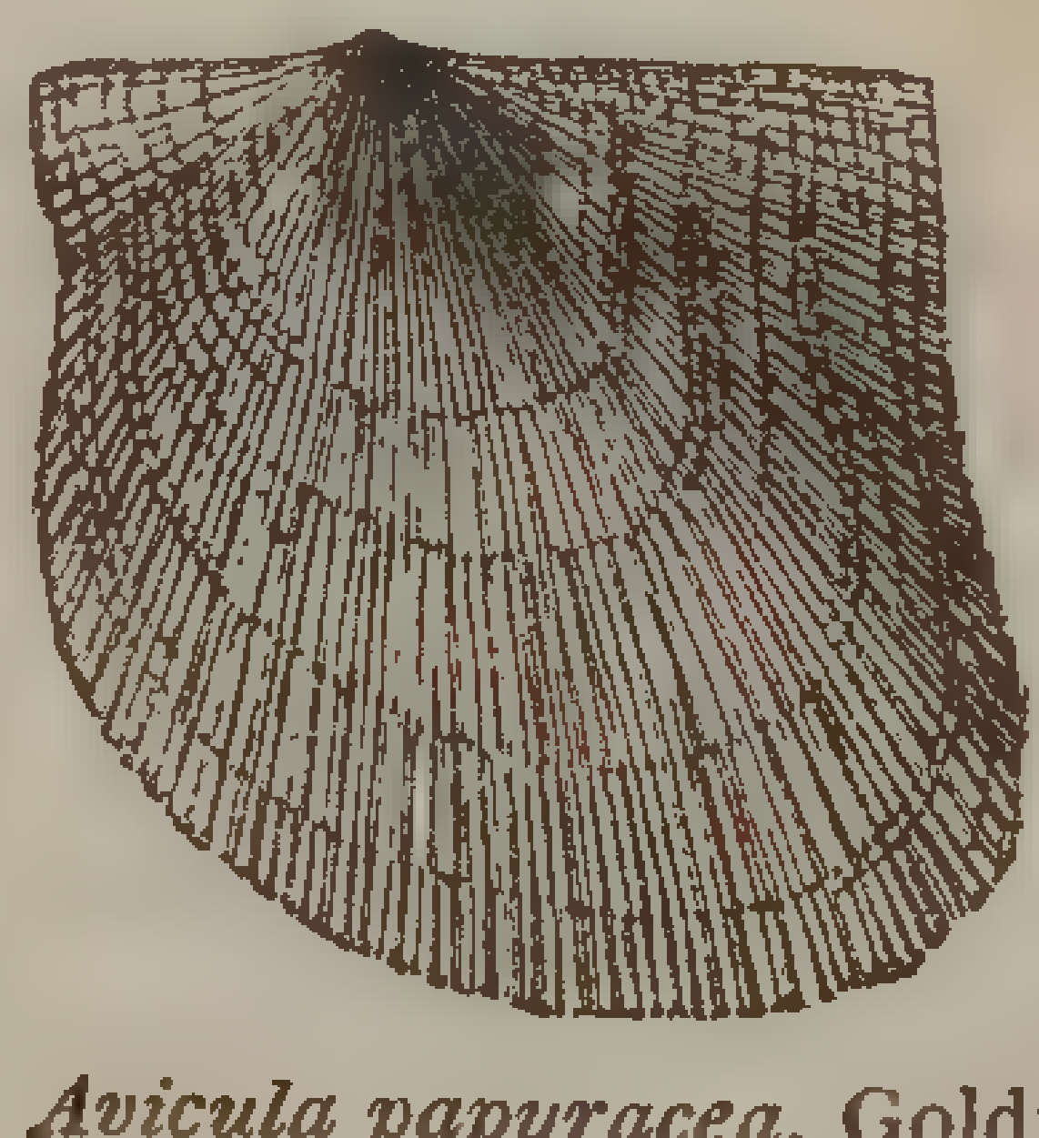
②

In the Edinburgh coal-field, at Burdiehouse, fossil fishes, mollusks, and cyprides (?), very similar to those in Shropshire and Staffordshire, have been found by Dr. Hibbert. In the coal-field also of Yorkshire there are freshwater strata, some of which contain shells referred to the genus *Unio;* but in the midst of the series there is one thin but very widely spread stratum, abounding in fishes and marine shells, such as *Goniatites Listeri* (fig. 503.), *Orthoceras*, and *Avicula papyracea*, Goldf. (fig. 504.)

Fig. 503.

Goniatites Listeri, Martin, sp.

Fig. 504.



Avicula papyracea, Goldf.
(*Pecten papyraceus*, Sow.)

No similarly intercalated layer of marine shells has been noticed in the neighbouring coal-field of Newcastle, where, as in South Wales and Somersetshire, the marine deposits are entirely below those containing terrestrial and freshwater remains.†

Clay-iron-stone.—Bands and nodules of clay-iron-stone are common in coal-measures, and are formed, says Sir H. De la Beche, of carbonate of iron mingled mechanically with earthy matter, like that constituting the shales. Mr. Hunt, of the Museum of Practical

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* Palæont. Dunker and V. Meyer, vol. iv. p. 17.

† Phillips; art. "Geology," Encyc. Metrop. p. 592.

Geology, instituted a series of experiments to illustrate the production of this substance, and found that decomposing vegetable matter, such as would be distributed through all coal-strata, prevented the farther oxidation of the proto-salts of iron, and converted the peroxide into protoxide by taking a portion of its oxygen to form carbonic acid. Such carbonic acid, meeting with the protoxide of iron in solution, would unite with it and form a carbonate of iron; and this mingling with fine mud, when the excess of carbonic acid was removed, might form beds or nodules of argillaceous iron-stone.*

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* Memoirs of Geol. Survey, pp. 51. 255, &c.

CHAPTER XXV.

CARBONIFEROUS GROUP—*continued.*

Coal-fields of the United States—Section of the country between the Atlantic and Mississippi—Position of land in the carboniferous period eastward of the Alleghanies—Mechanically formed rocks thinning out westward, and limestones thickening—Uniting of many coal-seams into one thick bed—Horizontal coal at Brownsville, Pennsylvania—Vast extent and continuity of single seams of coal—Ancient river-channel in Forest of Dean coal-field—Climate of carboniferous period—Insects in coal—Rarity of air-breathing animals—Great number of fossil fish—First discovery of the skeletons of fossil reptiles—Footprints of reptilians—First land-shell found—Rarity of air-breathers, whether vertebrate or invertebrate, in Coal-measures—Mountain limestone—Its corals and marine shells.

IT was stated in the last chapter that a great uniformity prevails in the fossil plants of the coal-measures of Europe and North America; and I may add that four-fifths of those collected in Nova Scotia have been identified with European species. Hence the former existence, at the remote period under consideration (the carboniferous), of a continent or chain of islands where the Atlantic now rolls its waves seems a fair inference. Nor are there wanting other and independent proofs of such an ancient land situated to the eastward of the present Atlantic coast of North America; for the geologist deduces the same conclusion from the mineral composition of the carboniferous and some older groups of rocks as they are developed on the eastern flanks of the Alleghanies, contrasted with their character in the low country to the westward of those mountains.

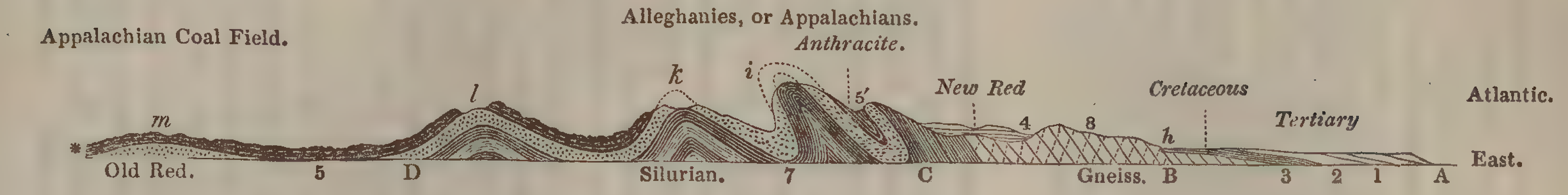
The annexed diagram (fig. 505.) will assist the reader in understanding the phenomena now alluded to, although I must guard him against supposing that it is a true section. A great number of details have of necessity been omitted, and the scale of heights and horizontal distances are unavoidably falsified.

Starting from the shores of the Atlantic, on the eastern side of the Continent, we first come to a low region (A B), which was called the alluvial plain by the first geographers. It is occupied by tertiary and cretaceous strata, before described (pp. 181. 232. and 255.), which are nearly horizontal. The next belt, from B to C, consists of granitic rocks (hypogene), chiefly gneiss and mica-schist, covered occasionally with unconformable red sandstone, No. 4. (New Red or Trias?), remarkable for its footprints (see p. 348.). Sometimes, also, this sandstone rests on the edges of the disturbed paleozoic rocks (as seen in the section). The region (B C), sometimes called the "Atlantic Slope," corresponds nearly in average width with the low and flat plain (A B), and is characterized by hills of moderate height, contrasting strongly, in their rounded shape and altitude, with the long,

Fig. 505.

Diagram explanatory of the geological structure of a part of the United States between the Atlantic and the Mississippi.

Length from E. to W. 850 miles.



Same section—*continued.*

A B. Atlantic plain.
B C. Atlantic slope.
C D. Alleghanies, or Appalachian chain.
D E. Appalachian coal-field west of the mountains.
E F. Dome-shaped out-crop of strata on the Ohio, older than the coal.
F G. Illinois coal-field.
h. Falls and rapids of the rivers at the junction of the hypogene and newer formations.
i, k, l, m. Parallel folds of the Appalachians, becoming successively more open and flatter in going from E. to W.

References to the different Formations.

1. Miocene tertiary.
2. Eocene tertiary.
3. Cretaceous strata.
4. Red sandstone with ornithichnites (new red or trias?) usually much invaded by trap.
5. Coal-measures (bituminous coal).
5′ Anthracitic coal-measures.
5″ Carboniferous limestone of the Illinois coal-field, wanting in the Appalachian.
6. Old red or Devonian, Olive slate, &c.
7. Primary fossiliferous or Silurian strata.
8. Hypogene strata, or gneiss, mica schist, &c., with granite veins.

Note. The dotted lines at *i* and *k* express portions of rock removed by denudation, the amount of which may be estimated by supposing similar lines prolonged from other points where different strata end abruptly at the surface.

N.B. The lower section at ** joins on to the upper one at *.

steep, and lofty parallel ridges of the Alleghany mountains. The out-crop of the strata in these ridges, like the two belts of hypogene and newer rocks (A B, and B C), above alluded to, when laid down on a geological map, exhibit long stripes of different colours, running in a N.E. and S.W. direction, in the same way as the lias, chalk, and other secondary formations in the middle and eastern half of England.

The narrow and parallel zones of the Appalachians, here mentioned, consist of strata, folded into a succession of convex and concave flexures, subsequently laid open by denudation. The component rocks are of great thickness, all referable to the Silurian, Devonian, and Carboniferous formations. There is no principal or central axis, as in the Pyrenees and many other chains — no nucleus to which all the minor ridges conform; but the chain consists of many nearly equal and parallel foldings, having what is termed an anticlinal and synclinal arrangement (see above, p. 48.). This system of hills extends, geologically considered, from Vermont to Alabama, being more than 100 miles long, from 50 to 150 miles broad, and varying in height from 2000 to 6000 feet. Sometimes the whole assemblage of ridges runs perfectly straight for a distance of more than 50 miles, after which all of them wheel round altogether, and take a new direction, at an angle of 20 or 30 degrees to the first.

We are indebted to the state surveyors of Virginia and Pennsylvania, Prof. W. B. Rogers and his brother Prof. H. D. Rogers, for the important discovery of a clue to the general law of structure prevailing throughout this range of mountains, which, however simple it may appear when once made out and clearly explained, might long have been overlooked, amidst so great a mass of complicated details. It appears that the bending and fracture of the beds is greatest on the south-eastern or Atlantic side of the chain, and the strata become less and less disturbed as we go westward, until at length they regain their original or horizontal position. By reference to the section (fig. 505.), it will be seen that on the eastern side, or in the ridges and troughs nearest the Atlantic, south-eastern dips predominate, in consequence of the beds having been folded back upon themselves, as in *i*, those on the north-western side of each arch having been inverted. The next set of arches (such as *k*) are more open, each having its western side steepest; the next (*l*) open out still more widely, the next (*m*) still more, and this continues until we arrive at the low and level part of the Appalachian coal-field (D E).

In nature or in a true section, the number of bendings or parallel folds is so much greater that they could not be expressed in a diagram without confusion. It is also clear that large quantities of rock have been removed by aqueous action or denudation, as will appear if we attempt to complete all the curves in the manner indicated by the dotted lines at *i* and *k*.

The movements which imparted so uniform an order of arrangement to this vast system of rocks must have been, if not contemporaneous. at least parts of one and the same series, depending on some common cause. Their geological date is well defined, at least within certain limits, for they must have taken place after the deposition of the carboniferous strata (No. 5.), and before the formation of the red sandstone (No. 4.). The greatest disturbing and denuding forces have evidently been exerted on the south-eastern side of the chain; and it is here that igneous or plutonic rocks are observed to have invaded the strata, forming dykes, some of which run for miles in lines parallel to the main direction of the Appalachians, or N.N.E. and S.S.W.

The thickness of the carboniferous rocks in the region C is very great, and diminishes rapidly as we proceed to the westward. The surveys of Pennsylvania and Virginia show that the south-east was the quarter whence the coarser materials of these strata were derived, so that the ancient land lay in that direction. The conglomerate which forms the general base of the coal-measures is 1500 feet thick in the Sharp Mountain, where I saw it (at C) near Pottsville; whereas it has only a thickness of 500 feet, about thirty miles to the north-west, and dwindles gradually away when followed still farther in the same direction, until its thickness is reduced to 30 feet.* The limestones, on the other hand, of the coal-measures augment as we trace them westward. Similar observations have been made in regard to the Silurian and Devonian formations in New York; the sandstones and all the mechanically-formed rocks thinning out as they go westward, and the limestones thickening, as it were, at their expense. It is, therefore, clear that the ancient land was to the east, where the Atlantic now is; the deep sea, with its banks of coral and shells to the west, or where the hydrographical basin of the Mississippi is now situated.

In that region, near Pottsville, where the thickness of the coal-measures is greatest, there are thirteen seams of anthracitic coal, several of them more than 2 yards thick. Some of the lowest of these alternate with beds of white grit and conglomerate of coarser grain than I ever saw elsewhere, associated with pure coal. The pebbles of quartz are often of the size of a hen's egg. On following these pudding-stones and grits for several miles from Pottsville, by Tamaqua, to the Lehigh Summit Mine, in company with Mr. H. D. Rogers, in 1841, he pointed out to me that the coarse-grained strata and their accompanying shales gradually thin out, until seven seams of coal, at first widely separated, are brought nearer and nearer together, until they successively unite; so that at last they form one mass, between 40 and 50 feet thick. I saw this enormous bed of anthracitic coal quarried in the open air at Mauch Chunk (or the Bear Mountain), the overlying sandstone, 40 feet thick, having been removed bodily from the top of the hill, which, to use the miner's expression, had been "scalped." The accumulation of vegetable matter now constituting this vast bed of anthracite, may perhaps,

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* H. D. Rogers, Trans. Assoc. Amer. Geol., 1840–42, p. 440.

before it was condensed by pressure and the discharge of its hydrogen, oxygen, and other volatile ingredients, have been between 200 and 300 feet thick. The origin of such a vast thickness of vegetable remains, so unmixed with earthy ingredients, can, I think, be accounted for in no other way, than by the growth, during thousands of years, of trees and ferns, in the manner of peat,—a theory which the presence of the Stigmaria *in situ* under each of the seven layers of anthracite, fully bears out. The rival hypothesis, of the drifting of plants into a sea or estuary, leaves the absence of sediment, or, in this case of sand and pebbles, wholly unexplained.

But the student will naturally ask, what can have caused so many seams of coal, after they had been persistent for miles, to come together and blend into one single seam, and that one equal in the aggregate to the thickness of the several separate seams? Often had the same question been put by English miners before a satisfactory answer was given to it by the late Mr. Bowman. The following is his solution of the problem. Let *a a′*, fig. 506., be a mass of vegetable matter, capable, when condensed, of forming a 3-foot seam of coal. It rests on the underclay *b b′*, filled with roots of trees *in situ*, and it supports a growing forest (C D). Suppose that part of the same forest D E had become submerged by the ground sinking down 25 feet, so that the trees have been partly thrown down and partly remain erect in water, slowly decaying, their stumps and the lower parts of their trunks being enveloped in layers of sand and mud, which are gradually filling up the lake D F. When this lake or lagoon has at length been entirely silted up and converted into land, say, in the course of a century, the forest C D will extend once more continuously over the whole area C F, as in fig. 507., and another mass of vegetable matter (*g g′*), forming 3 feet more of coal, may accumulate from C to F. We then find in the region F, two seams of coal (*a′* and *g′*) each 3 feet thick, and separated by 25 feet of sandstone and shale, with erect trees based upon the lower coal, while, between D and C, we find these two seams united into a 2-yard coal. It may be objected that the uninterrupted growth of plants during the interval of a century will have caused the vegetable matter in

Fig. 506.

Fig. 507.

the region C D to be thicker than the two distinct seams a' and g' at F; and no doubt there would actually be a slight excess representing one generation of trees with the remains of other plants, forming half an inch or an inch of coal; but this would not prevent the miner from affirming that the seam *a g*, throughout the area C D, was equal to the two seams a' and g' at F.

The reader has seen, by reference to the section (fig. 505. p. 392.), that the strata of the Appalachian coal-field assume an horizontal position west of the mountains. In that less elevated country, the coal-measures are intersected by three great navigable rivers, and are capable of supplying for ages, to the inhabitants of a densely peopled region, an inexhaustible supply of fuel. These rivers are the Monongahela, the Alleghany, and the Ohio, all of which lay open on their banks the level seams of coal. Looking down the first of these at Brownsville, we have a fine view of the main seam of bituminous coal 10 feet thick, commonly called the Pittsburg seam, breaking out in the steep cliff at the water's edge; and I made the accompanying sketch of its appearance from the bridge over the river (see fig. 508.). Here the coal, 10 feet thick, is covered by carbonaceous shale (*b*), and this again by micaceous sandstone (*c*). Horizontal galleries may be driven everywhere at very slight expense, and so worked as to drain themselves, while the cars, laden with coal and attached to each other, glide down on a railway, so as to deliver their burden into barges moored to the river's bank. The same seam is seen at a distance, on the right bank (at *a*), and may be followed the whole way to Pittsburg, fifty miles distant. As it is nearly horizontal, while the river descends it crops out at a continually increasing, but never at an inconvenient, height above the Monongahela. Below the great bed of coal at Brownsville is a fire-clay 18 inches thick, and below this, several beds of limestone, below which again are other coal seams. I have also shown in my sketch another layer of workable coal (at *d d*), which breaks out on the slope of the hills at a greater height. Here almost every proprietor can open a coal-pit on his own land, and the stratification being very regular, he may calculate with precision the depth at which coal may be won.

The Appalachian coal-field, of which these strata form a part (from C to E, section, fig. 505., p. 392.), is remarkable for its vast area; for, according to Professor H. D. Rogers, it stretches continuously from N.E. to S.W., for a distance of 720 miles, its greatest width being about 180 miles. On a moderate estimate, its superficial area amounts to 63,000 square miles.

This coal-formation, before its original limits were reduced by denudation, must have measured 900 miles in length, and in some places more than 200 miles in breadth. By again referring to the section (fig. 505., p. 392.), it will be seen that the strata of coal are horizontal to the westward of the mountains in the region D E, and become more and more inclined and folded as we proceed eastward. Now it is invariably found, as Professor H. D. Rogers has shown by

View of the great Coal Seam on the Monongahela at Brownsville, Pennsylvania, U. S.

a. Ten-foot seam of coal.
b. Black bituminous or carbonaceous shale, 10 feet thick.
c. Micaceous sandstone.
d d. Upper seam of coal, 6 feet thick.

chemical analysis, that the coal is most bituminous towards its western limit, where it remains level and unbroken, and that it becomes progressively debituminized as we travel south-eastward towards the more bent and distorted rocks. Thus, on the Ohio, the proportion of hydrogen, oxygen, and other volatile matters ranges from forty to fifty per cent. Eastward of this line, on the Monongаhela, it still approaches forty per cent., where the strata begin to experience some gentle flexures. On entering the Alleghany Mountains, where the distinct anticlinal axes begin to show themselves, but before the dislocations are considerable, the volatile matter is generally in the proportion of eighteen or twenty per cent. At length, when we arrive at some insulated coal-fields (5′, fig. 505.) associated with the boldest flexures of the Appalachian chain, where the strata have been actually turned over, as near Pottsville, we find the coal to contain only from six to twelve per cent. of bitumen, thus becoming a genuine anthracite.*

It appears from the researches of Liebig and other eminent chemists, that when wood and vegetable matter are buried in the earth exposed to moisture, and partially or entirely excluded from the air, they decompose slowly and evolve carbonic acid gas, thus parting with a portion of their original oxygen. By this means, they become gradually converted into lignite or wood-coal, which contains a larger proportion of hydrogen than wood does. A continuance of decomposition changes this lignite into common or bituminous coal, chiefly by the discharge of carburetted hydrogen, or the gas by which we illuminate our streets and houses. According to Bischoff, the inflammable gases which are always escaping from mineral coal, and are so often the cause of fatal accidents in mines, always contain carbonic acid, carburetted hydrogen, nitrogen, and olifiant gas. The disengagement of all these gradually transforms ordinary or bituminous coal into anthracite, to which the various names of splint-coal, glance-coal, hard-coal, culm, and many others, have been given.

We have seen that, in the Appalachian coal-field, there is an intimate connection between the extent to which the coal has parted with its gaseous contents, and the amount of disturbance which the strata have undergone. The coincidence of these phenomena may be attributed partly to the greater facility afforded for the escape of volatile matter, where the fracturing of the rocks had produced an infinite number of cracks and crevices, and also to the heat of the gases and water penetrating these cracks, when the great movements took place, which have rent and folded the Appalachian strata. It is well known that, at the present period, thermal waters and hot vapours burst out from the earth during earthquakes, and these would not fail to promote the disengagement of volatile matter from the carboniferous rocks.

Continuity of seams of coal.—As single seams of coal are continuous over very wide areas, it has been asked, how forests could have prevailed uninterruptedly over such wide spaces. In reply, it may be said that swamp-forests in one delta may extend for 25, 50, or 100 miles, while in a contiguous delta, as on the borders of the Gulf of Mexico, another of precisely the same character may be growing; and these may in after ages appear to geologists to have

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* Trans. of Assoc. of Amer. Geol., p. 470.

been continuous, although in fact they were simply contemporaneous. Denudation may easily be imagined in such cases as the cause of interruptions, which were in fact, original. But as in all the American coal-fields there are numerous root-beds without any superincumbent coal, we may presume that frequently layers of vegetable matter were removed by floods; and in other cases, where the stigmaria-clays are for a certain space covered with coal, and then prolonged without any such covering, the inference of partial denudation is still more obvious.

In the Forest of Dean, ancient river-channels are found, which pass through beds of coal, and in which rounded pebbles of coal occur. They are of older date than the overlying and undisturbed coal-measures. The late Mr. Buddle, who described them to me, told me he had seen similar phenomena in the Newcastle coal-field. Nevertheless, instances of these channels are much more rare than we might have anticipated, especially when we remember how often the roots of trees (*Stigmariæ*) have been torn up, and drifted in broken fragments into the grits and sandstones. The prevalence of a downward movement is, no doubt, the principal cause which has saved so many extensive seams of coal from destruction by fluviatile action.

Climate of Coal Period. — So long as the botanist taught that a tropical climate was implied by the carboniferous flora, geologists might well be at a loss to reconcile the preservation of so much vegetable matter with a high temperature; for heat hastens the decomposition of fallen leaves and trunks of trees, whether in the atmosphere or in water. It is well known that peat, so abundant in the bogs of high latitudes, ceases to grow in the swamps of warmer regions. It seems, however, to have become a more and more received opinion, that the coal-plants do not, on the whole, indicate a climate resembling that now enjoyed in the equatorial zone. Tree-ferns range as far south as the southern part of New Zealand, and Araucarian pines occur in Norfolk Island. A great predominance of ferns and lycopodiums indicates moisture, equability of temperature, and freedom from frost, rather than intense heat; and we know too little of the sigillariæ, calamites, asterophyllites, and other peculiar forms of the carboniferous period, to be able to speculate with confidence on the kind of climate they may have required.

The same may be said of the corals and cephalopoda of the Mountain Limestone, —they belong to families of whose climatal habits we know nothing; and even if they should be thought to imply that a warm temperature characterized the northern seas in the carboniferous era, the absence of cold may have given rise (as at present in the seas of the Bermudas, under the influence of the gulf-stream) to a very wide geographical range of stone-building corals and shell-bearing cuttle-fish, without its being necessary to call in the aid of tropical heat.

CARBONIFEROUS REPTILES.

Where we have evidence in a single coal-field, as in that of Nova Scotia, or of South Wales, of fifty or even a hundred ancient forests buried one above the other, with the roots of trees still in their original position, and with some of the trunks still remaining erect, we are apt to wonder that until the year 1844 no remains of contemporaneous air-breathing creatures should have been discovered. No vertebrated animals more highly organized than fish, no mammalia or birds, no saurians, frogs, tortoises, or snakes were known in rocks of such high antiquity. In the coal-fields of Europe mention has been made of beetles, locusts, and a few other insects, but no land-shells have even now been met with. Agassiz described in his great work on fossil fishes more than one hundred and fifty species of ichthyolites from the coal-strata, ninety-four belonging to the families of shark and ray, and fifty-eight to the class of ganoids. Some of these fish are very remote in their organization from any now living, especially those of the family called *Sauroid* by Agassiz; as *Megalichthys*, *Holoptychius*, and others, which were often of great size, and all predaceous. Their osteology, says M. Agassiz, reminds us in many respects of the skeletons of saurian reptiles, both by the close sutures of the bones of the skull, their large conical teeth striated longitudinally (see fig. 509.), the articulations of the spinous processes with the vertebræ, and other characters. Yet they do not form a family intermediate between fish and reptiles, but are true *fish*, though doubtless more highly organized than any living fish.*

Fig. 509.

Holoptychius Hibberti, Ag.
Fifeshire coal-field.
Tooth; natural size.

The annexed figure represents a large tooth of the *Holoptychius*, found by Mr. Horner in the Cannel coal of Fifeshire. This fish probably inhabited an estuary, like many of its contemporaries, and frequented both rivers and the sea.

At length, in 1844, the first skeleton of a true reptile was announced from the coal of Münster-Appel in Rhenish Bavaria, by H. von Meyer, under the name of *Apateon pedestris*, the animal being supposed to be nearly related to the salamanders. Three years later, in 1847, Prof. von Dechen found in the coal-field of Saarbrück, at the village of Lebach, between Strasburg and Treves, the skeletons of no less than three distinct species of air-breathing reptiles, which were described by the late Prof. Goldfuss under the generic name of *Archegosaurus*. The ichthyolites and plants found in the same strata left no doubt that these remains belonged to the true coal period. The skulls, teeth, and the greater portions of the skeleton, nay, even a large part of the skin, of two

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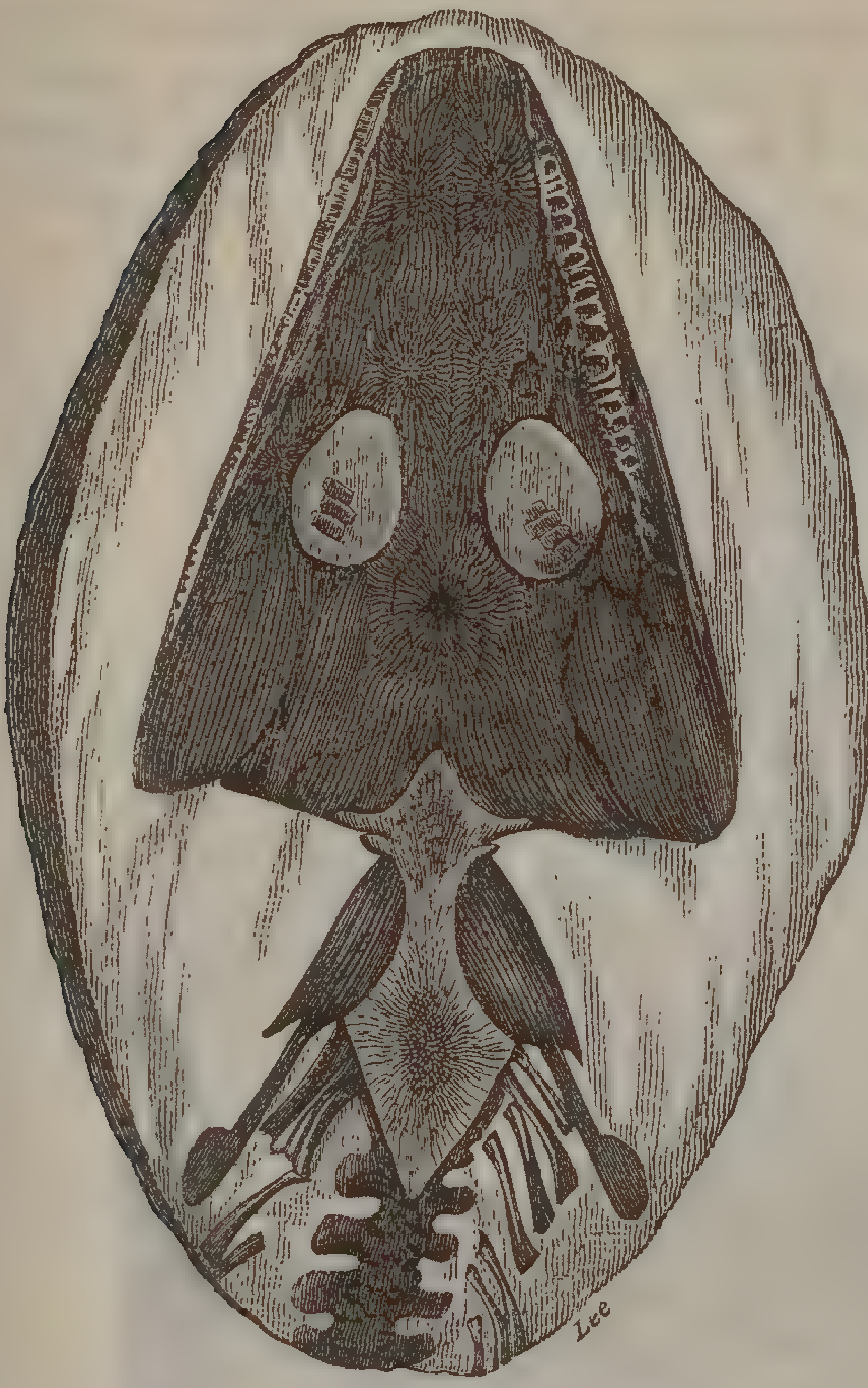
* Agassiz, Poiss. Foss. vol. ii. p. 88, &c.

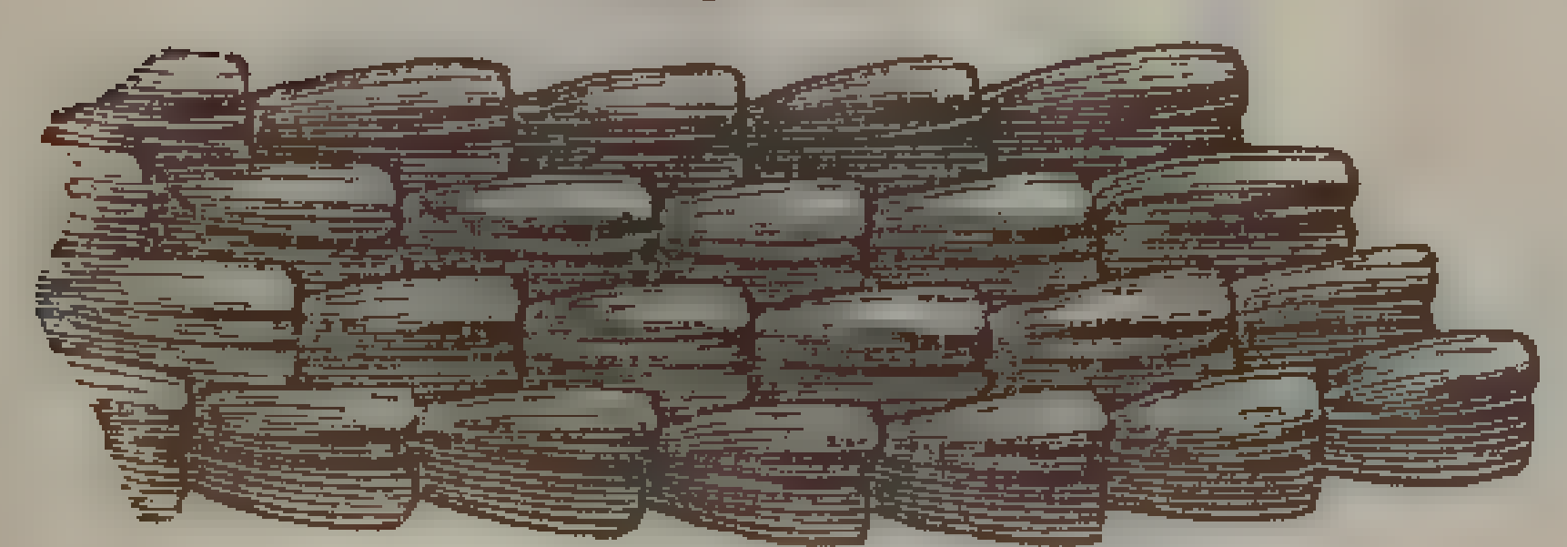
Fig. 510.



Archegosaurus minor, Goldfuss. Fossil reptile from the coal-measures, Saarbrück.

of these reptiles have been faithfully preserved in the centre of spheroidal concretions of clay-iron-stone. The largest of these lizards, *Archegosaurus Decheni*, must have been 3 feet 6 inches long. The annexed drawing represents the skull and neck bones of the smallest of the three, of the natural size. They were considered by Goldfuss as saurians, but by Herman von Meyer as most nearly allied to the *Labyrinthodon*, and therefore, as before explained (p. 342.), having many characters intermediate between batrachians and saurians. The remains of the extremities leave no doubt that they were quadrupeds, "provided," says Von Meyer, "with hands and feet terminating in distinct toes; but these limbs were weak, serving only for swimming or creeping." The same anatomist has pointed out certain points of analogy between their bones and those of the *Proteus anguinus;* and Prof. Owen has observed to me that they make an approach to the *Proteus* in the shortness of their ribs. Two specimens of these ancient reptiles retain a large part of the outer skin, which consisted of long, narrow wedge-shaped, tile-like, and horny scales, arranged in rows (see fig. 511.).

Fig. 511.



Imbricated covering of skin of *Archegosaurus medius*, Goldf.; magnified.*

Cheirotherian footprints in coal-measures, United States. — In 1844, the very year when the Apateon or Salamander of the coal was first met with in the country between the Moselle and the Rhine, Dr. King published an account of the footprints of a large reptile discovered by him in North America. These occur in the coal-strata of Greensburg, in Westmoreland County, Pennsylvania; and I had an opportunity of examining them in 1846. I was at once convinced of their genuineness, and declared my conviction on that

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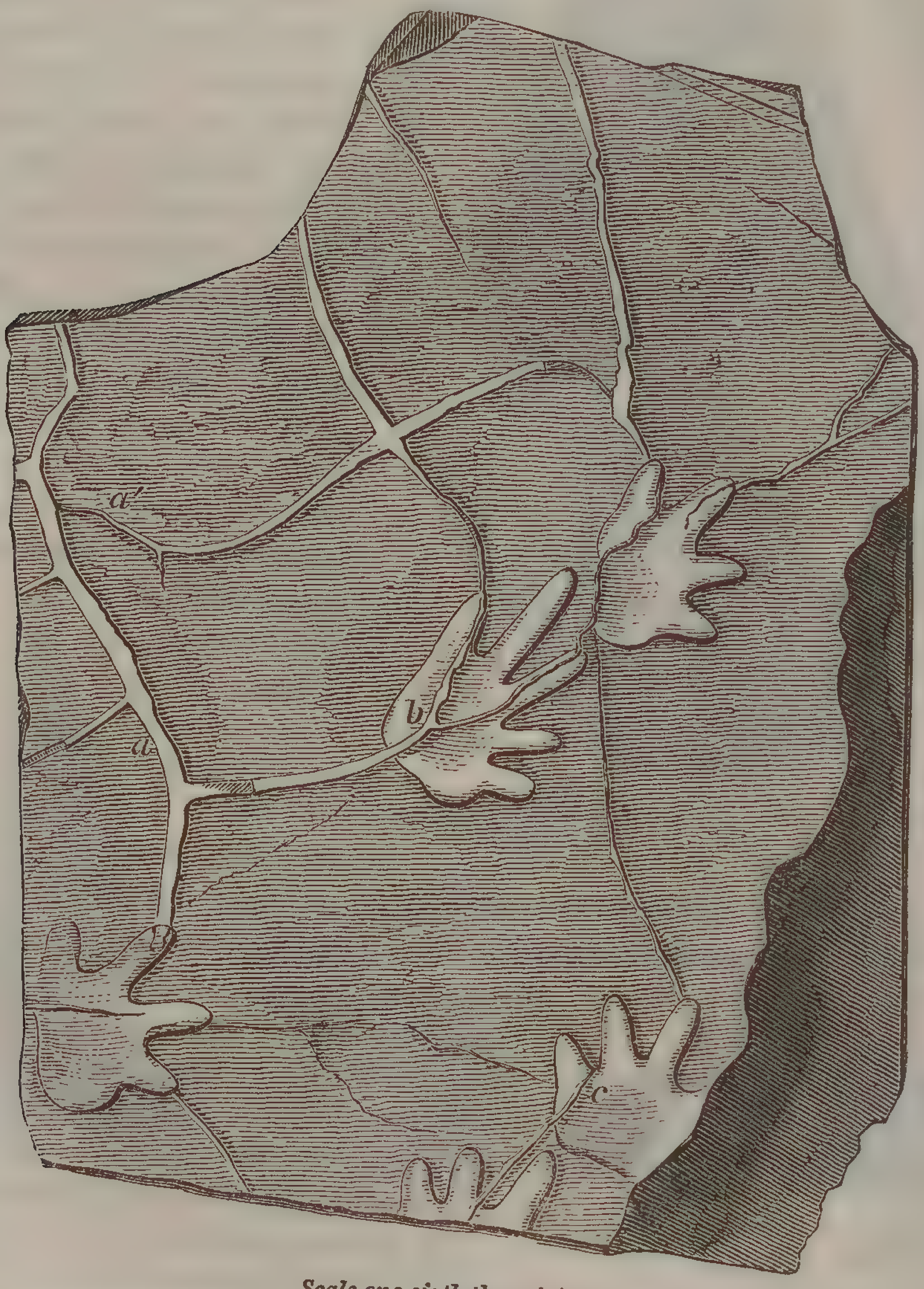
* Goldfuss, Neue Jenaische Lit. Zeit., 1848; and Von Meyer, Quart. Geol. Journ., vol. iv. Miscell. p. 51.

point, on which doubts had been entertained both in Europe and the United States. The footmarks were first observed standing out in relief from the lower surface of slabs of sandstone, resting on thin layers of fine unctuous clay. I brought away one of these masses, which is represented in the accompany drawing (fig. 512.). It displays, together with footprints, the casts of cracks (a, a') of various sizes. The origin of such cracks in clay, and casts of the same, has before been explained, and referred to the drying and shrinking of mud, and the subsequent pouring of sand into open crevices. It will be seen that some of the cracks, as at b, c, traverse the footprints, and produce distortion in them, as might have been expected, for the mud must have been soft when the animal walked over it and left the impressions; whereas, when it afterwards dried up and shrank, it would be too hard to receive such indentations.

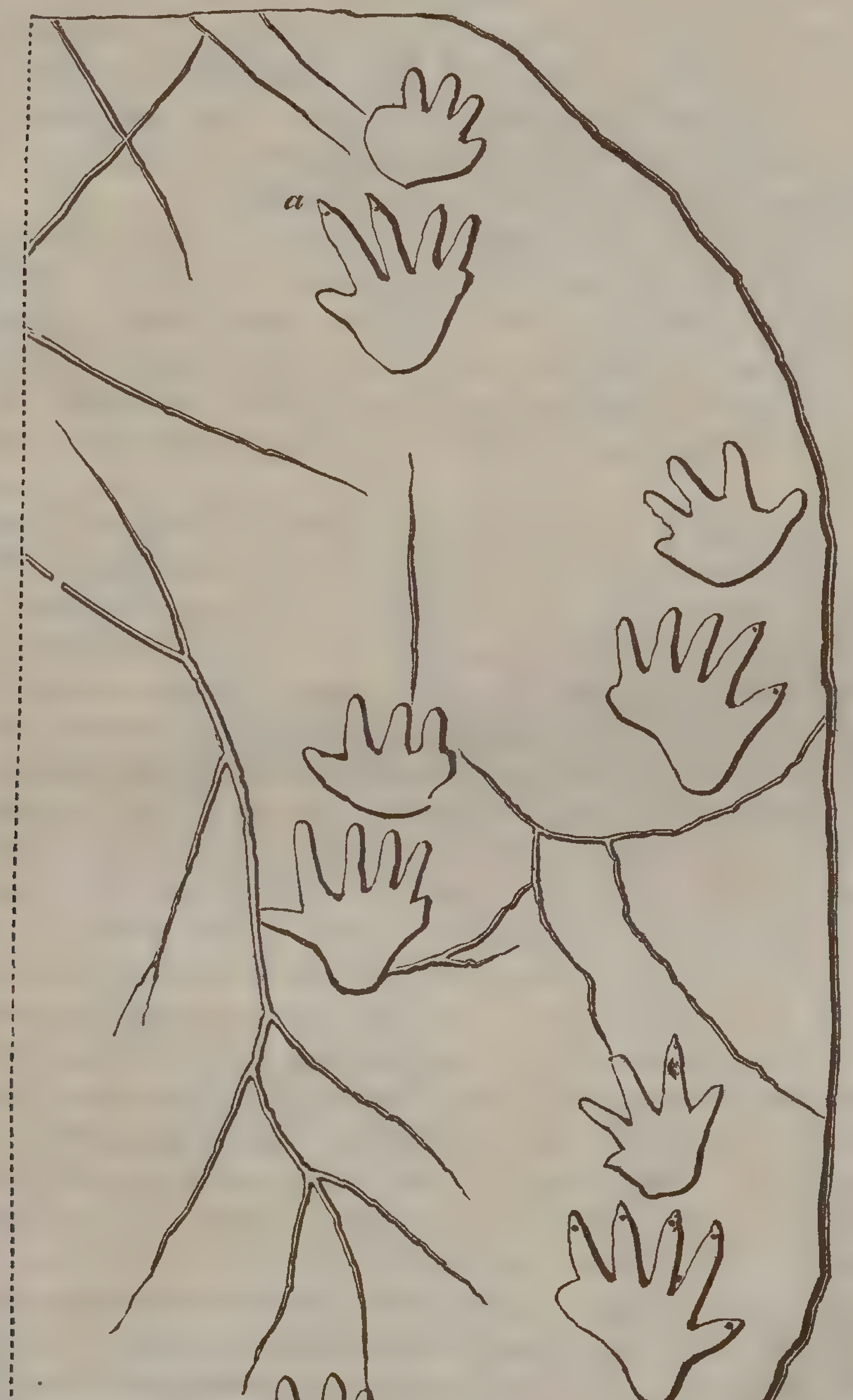
Fig. 512.



Scale one-sixth the original.
Slab of sandstone from the coal-measures of Pennsylvania, with footprints of air-breathing reptile and casts of cracks.

No less than twenty-three footsteps were observed by Dr. King in the same quarry before it was abandoned, the greater part of them so arranged (see fig. 513.) on the surface of one stratum as to imply

Fig. 513.



Series of reptilian footprints in the coal-strata of Westmoreland County, Pennsylvania.
a. Mark of nail ?

that they were made successively by the same animal. Everywhere there was a double row of tracks, and in each row they occur in pairs, each pair consisting of a hind and fore foot, and each being at nearly equal distances from the next pair. In each parallel row the toes turn the one set to the right, the other to the left. In the European *Cheirotherium*, before mentioned (p. 339.), both the hind and the fore feet have each five toes, and the size of the hind foot is about five times as large as the fore foot. In the American fossil the posterior footprint is not even twice as large as the anterior, and the number of toes is unequal, being five in the hinder and four in the anterior foot. In this, as in the European *Cheirotherium*, one toe stands out like a thumb, and these thumb-like toes turn the one set to the right, and the other to the left. The American *Cheirotherium* was evidently a broader animal, and belonged to a distinct genus from that of the triassic age in Europe.*

We may assume that the reptile which left these prints on the ancient sands of the coal-measures was an air-breather, because its weight would not have been sufficient under water to have made impressions so deep and distinct. The same conclusion is also borne out by the casts of the cracks above described, for they show that the clay had been exposed to the air and sun, so as to have dried and shrunk.

The geological position of the sandstone of Greensburg is perfectly clear, being situated in the midst of the Appalachian coal-field, having the main bed of coal, called the Pittsburg seam, above mentioned (p. 396.), 3 yards thick, 100 feet above it, and worked in the neighbourhood, with several other seams of coal at lower levels. The impressions of *Lepidodendron*, *Sigillaria*, *Stigmaria*, and other characteristic carboniferous plants are found both above and below the level of the reptilian footsteps.

Analogous footprints of a large reptile of still older date were afterwards found (1849) at Pottsville, 70 miles N.E. of Philadelphia, by Mr. Isaac Lea, in a formation of red shales, called No. XI. by Prof. H. D. Rogers, in the State Survey of Pennsylvania, and referred by him to the base of the coal, but regarded by some geologists as the uppermost part of the Old Red Sandstone. A thickness of 1700 feet of strata intervenes between the footprints of Greensburg, before described, and these older Pottsville impressions. In the same Red Shale, No. XI., the "debateable ground" between the Carboniferous and Devonian group, Prof. H. D. Rogers announced in 1851 that he had discovered other footprints, referred by him to three species of quadrupeds, all of them five-toed and in double rows, with an opposite symmetry, as if made by right and left feet, while they likewise display the alternation of fore foot and hind foot. One species, the largest of the three, presents a diameter for each footprint of about two inches, and shows the fore and hind feet to be nearly equal in dimensions. It exhibits a length of stride of about nine inches, and a breadth between the right and left footsteps of nearly four inches. The impressions of the hind feet are but little in the rear of the fore feet. The animal which made them is supposed to have been allied to a Saurian, rather than to a Batrachian or Chelonian. With these footmarks were seen shrinkage cracks, such as are caused by the sun's heat in mud, and rain-spots, with the signs of the trickling of water on a wet, sandy beach; all

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* See Lyell's Second Visit, &c., vol. ii. p. 305.

confirming the conclusion derived from the footprints, that the quadrupeds belonged to air-breathers, and not to aquatic races.

In 1852 the first osseous remains of a reptile were obtained from the coal-measures of America by Mr. Dawson and myself. We detected them in the interior of one of the erect Sigillariæ before alluded to as of such frequent occurrence in Nova Scotia. The tree was about two feet in diameter, and consisted, as usual, of an external cylinder of bark, converted into coal, and an internal stony axis of black sandstone, or rather mud and sand stained black by carbonaceous matter, and cemented together with fragments of wood into a rock. These fragments were in the state of charcoal, and seem to have fallen to the bottom of the hollow tree while it was rotting away. The skull, jaws, and vertebræ of a reptile, probably about 2½ feet in length (*Dendrerpeton Acadianum*, Owen), were scattered through this stony matrix. The shell also of a *Pupa*, the first pulmoniferous mollusk ever met with in the coal, was observed in the same stony mass. Dr. Wyman of Boston pronounced the reptile to be allied in structure to *Menobranchus* and *Menopoma*, species of batrachians, now inhabiting the North American rivers. The same view was afterwards confirmed by Prof. Owen, who also pointed out the resemblance of the cranial plates to those seen in the skull of *Archegosaurus* and *Labyrinthodon*.* Whether the creature had crept into the hollow tree while its top was still open to the air, or whether it was washed in with mud during a flood, or in whatever other manner it entered, must be matter of conjecture.

Footprints of two reptiles of different sizes had previously been observed by Dr. Harding and Dr. Gesner on ripple-marked flags of the lower coal-measures in Nova Scotia, evidently made by quadrupeds walking on the ancient beach, or out of the water, just as the recent Menopoma is sometimes observed to do.

In 1853 Prof. Owen announced the first discovery of fossil reptilian remains in the British Coal-Measures; and, in 1854, the same osteologist described a "sauroid batrachian," of the *Labyrinthodon* family, obtained by Mr. Dawson, from the coal of Pictou in Nova Scotia.

Thus in ten years (between 1844 and 1854) the skeletons or bones of no less than seven carboniferous reptiles, referred to five genera, were brought to light; to say nothing of numerous reptilian footprints, some of them too large to belong to the same species as the bones.

Rarity of vertebrate and invertebrate Air-breathers in Coal.

Before the earliest date above mentioned (1844) it was common to hear geologists insisting on the non-existence of vertebrate animals of a higher grade than fishes in the Coal, or in any rocks older than the Permian. Even now, it may be said, that we have scarcely made any progress in obtaining a knowledge of the terrestrial fauna

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* Geol. Quart. Journ. vol. ix. p. 58.

of the coal, since the reptiles above enumerated seem to have been all amphibious. Negative evidence should have its due weight in paleontological reasonings and speculations, but we are as yet quite unable to appreciate its value. In the United States, about 5 millions of tons of native coal are annually extracted from the coal-measures, yet no fossil insect has yet been met with in the carboniferous rocks of North America. Ought we then to conclude that at the period of the coal insects were unrepresented in the forests of the Western World? In like manner, no land-shell, no Helix, Bulimus, Pupa, or Clausilia, nor any aquatic pulmoniferous mollusk, such as Limneus or Planorbis, is recorded to have come from the coal of Europe, worked for centuries before America was discovered, and now quarried on so enormous a scale. Can we infer that land-shells were not called into existence in European latitudes, until after the carboniferous period?

The theory of progressive development would account readily for the absence of Chelonian and Saurian reptiles, or of Birds and Mammals, from the Coal-Measures, because the condition of the planet is supposed to have been too immature and unsettled to permit creatures enjoying a higher development than batrachians to find a fit domicile therein. But this same theory leaves the scarcity of the invertebrata, or the entire absence of many important classes of them, wholly unexplained. When we generalize on this subject, we must not forget that the eighteen or twenty individual insects and land-shells met with in the coal (and most of these very recently found), are scarcely double the number of the carboniferous reptiles which have been established within the last ten years on the evidence of bones and footprints. Yet our opportunities of examining strata formed in close connection with ancient land exceed in this case all that we enjoy in regard to any other formations, whether primary, secondary, or tertiary. We have ransacked hundreds of soils replete with the fossil roots of trees, — have dug out hundreds of erect trunks and stumps, which stood in the position in which they grew, — have broken up myriads of cubic feet of fuel still retaining its vegetable structure, — and, after all, we continue almost as much in the dark respecting the invertebrate air-breathers of this epoch, as if the Coal had been thrown down in mid-ocean. The age of the planet, or its unprepared state to serve as a dwelling place for organized beings, cannot explain the enigma, because we know that while the land supported a luxuriant vegetation, the contemporaneous seas swarmed with life—with Articulata, Mollusca, Radiata, and Fishes. We must, therefore, collect more facts, if we expect to solve a problem, which, in the present state of science, cannot but excite our wonder; and we must remember how much the conditions of this problem have varied within the last ten years. Meanwhile let us be content to impute the scantiness of our data chiefly to our want of skill as collectors and interpreters, but partly also to our ignorance of the laws which govern the fossilization of land-animals, whether of high or low degree.

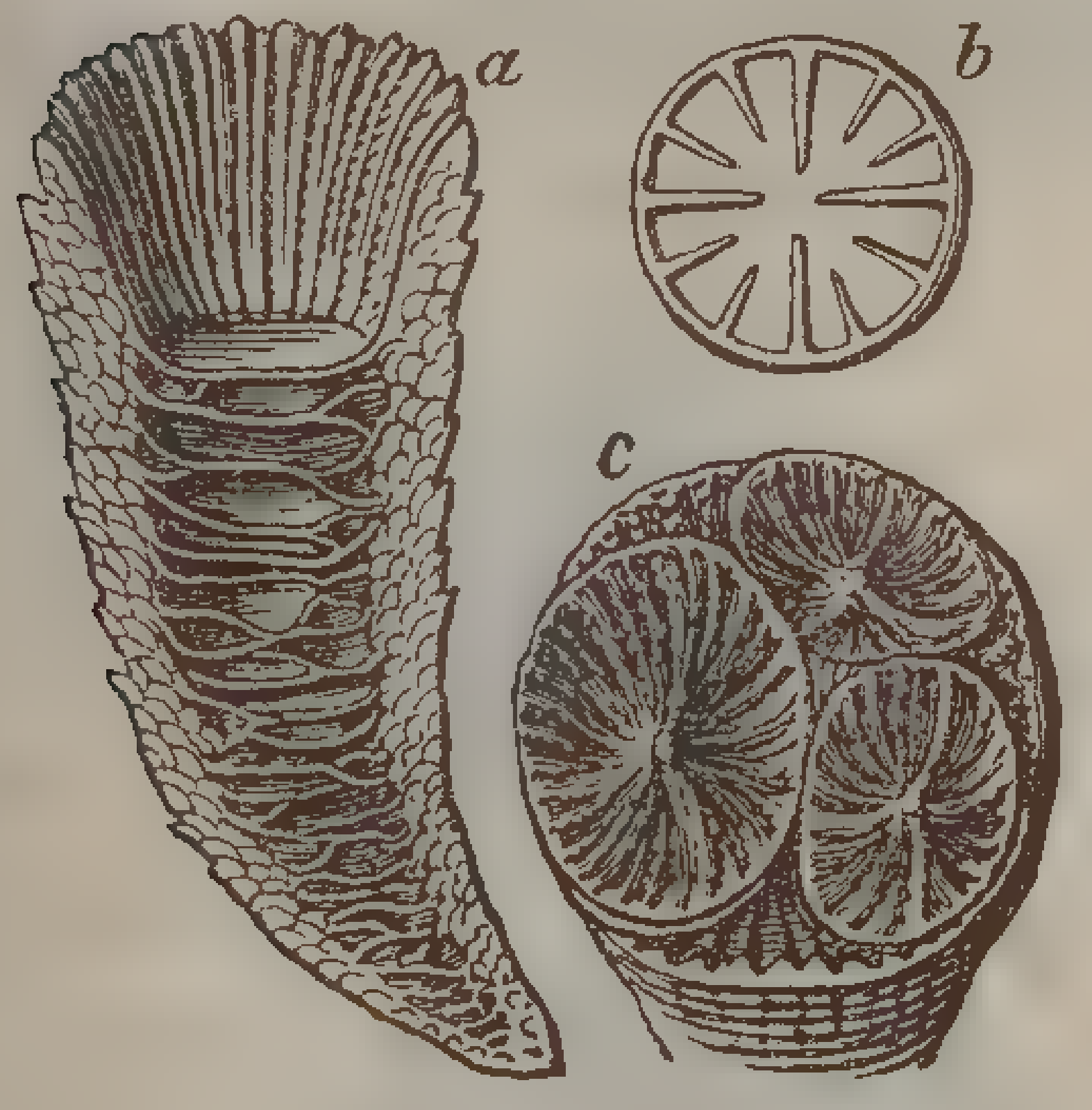
CARBONIFEROUS OR MOUNTAIN LIMESTONE.

It has been already stated (p. 362.), that this formation underlies the Coal-Measures in the South of England and Wales, whereas in the North and in Scotland marine limestones alternate with Coal-Measures, or with shales and sandstones, sometimes containing seams of Coal. In its most calcareous form the Mountain Limestone is destitute of land-plants, and is loaded with marine remains, — the greater part indeed of the rock being made up bodily of corals and crinoids.

The Corals deserve especial notice, as the cup-shaped kinds, which have the most massive and stony skeletons, display peculiarities of structure by which they may be distinguished, as MM. Milne Edwards and Haime first pointed out, from all species found in strata newer than the Permian. There is, in short, an ancient or *Paleozoic*, and a modern or *Neozoic* type, if, by the latter term, we designate (as proposed by Prof. E. Forbes) all strata from the triassic to the most modern, inclusive. The accompanying diagrams (figs. 514, 515.) may illustrate these types; and, although it may not always be easy for any but a practised naturalist to recognise the points of structure here described, every geologist should understand them, as the reality of the distinction is of no small theoretical interest.

Fig. 514.

Paleozoic type of lamelliferous cup-shaped Coral. Order ZOANTHARIA RUGOSA, Milne Edwards and Jules Haime.



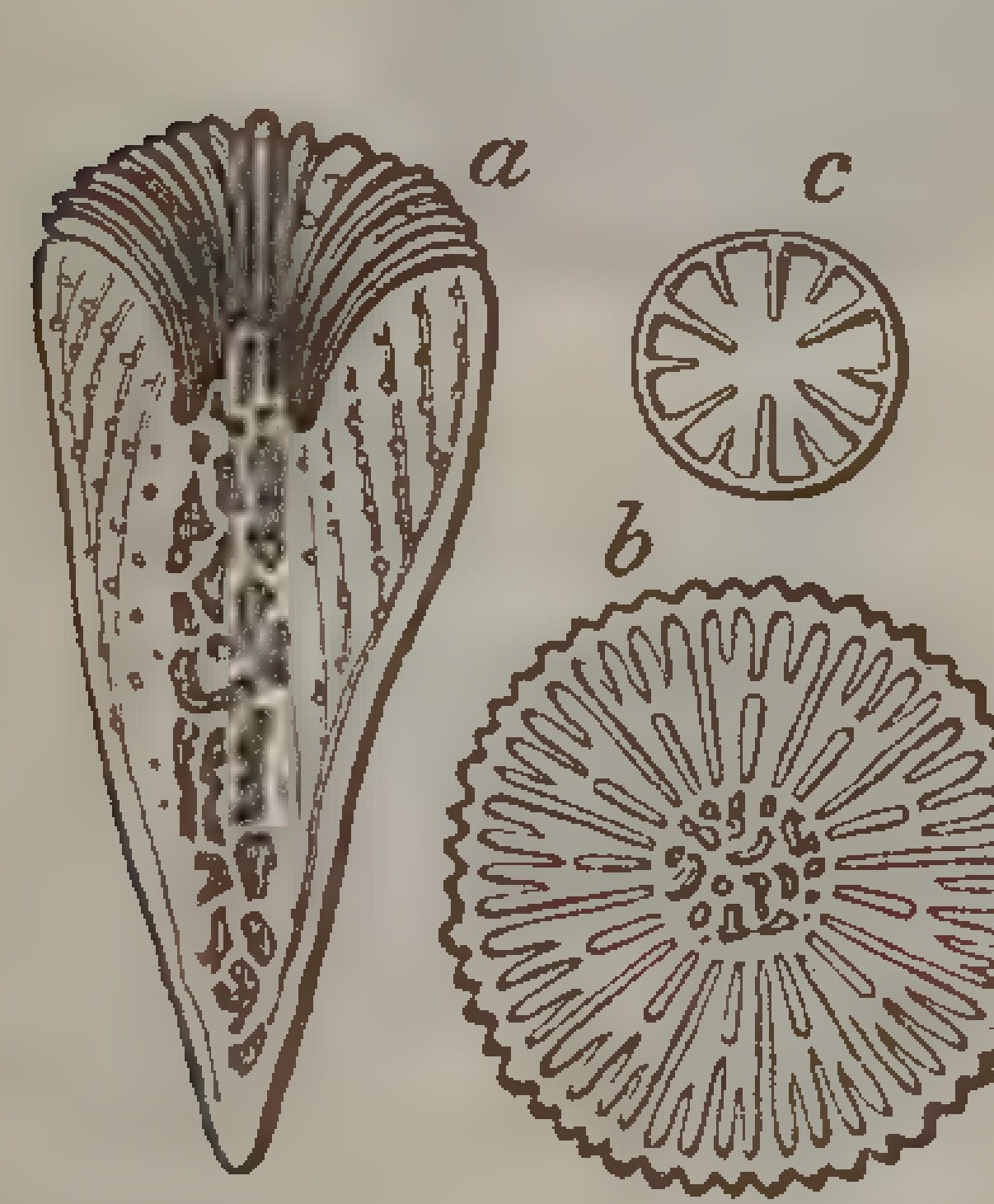
a. Vertical section of *Campophyllum flexuosum* (*Cyathophyllum*, Goldfuss); ½ nat. size: from the Devonian of the Eifel. The *lamellæ* are seen around the inside of the cup; the walls consist of cellular tissue; and large transverse plates, called *tabulæ*, divide the interior into chambers.

b. Arrangement of the *lamellæ* in *Polycœlia profunda*, Germar, sp.; nat. size: from the Magnesian Limestone, Durham. This diagram shows the quadripartite arrangement of the lamellæ characteristic of paleozoic corals, there being 4 principal and 8 intermediate lamellæ, the whole number in this type being always a multiple of four.

c. *Stauria astrææformis*, Milne Edwards. Young group, nat. size. Upper Silurian, Gothland. The lamellæ in each cup are divided by 4 prominent ridges into 4 groups.

Fig. 515.

Neozoic type of lamelliferous cup-shaped Coral. Order ZOANTHARIA APOROSA, M. Edwards and J. Haime.



a. *Parasmilia centralis*, Mantell, sp. Vertical section, nat. size. Upper Chalk, Gravesend. In this type the *lamellæ* are massive, and extend to the axis of loose cellular tissue, without any transverse plates like those in fig. 514. *a*.

b. *Cyathina Bowerbankii*, Edwards and Haime. Transverse section, enlarged. Gault, Folkstone. In this coral the *lamellæ* are a multiple of six. The twelve principal plates reach the central axis or columella, and between each pair there are three secondary plates, in all forty-eight. The short intermediate plates which proceed from the columella are not counted. They are called *pali*.

c. *Fungia patellaris*, Lamk. Recent: very young state. Diagram of its six principal and six intermediate septa, magnified. The sextuple arrangement is always more manifest in the young than in the adult state.

[illegible]

It will be seen, that the more ancient corals have what is called a quadripartite arrangement of the stony plates or *lamellæ*,—parts of the skeleton which support the organs of reproduction. The number of these lamellæ in the paleozoic type is 4, 8, 16, &c.; while in the newer type the number is always 6, 12, 24, or some other multiple of six; and this holds good, whether they be simple cup-like forms, as in figs. 514. *a* and 515. *a*, or aggregate clusters of cups as in 514. *c*.

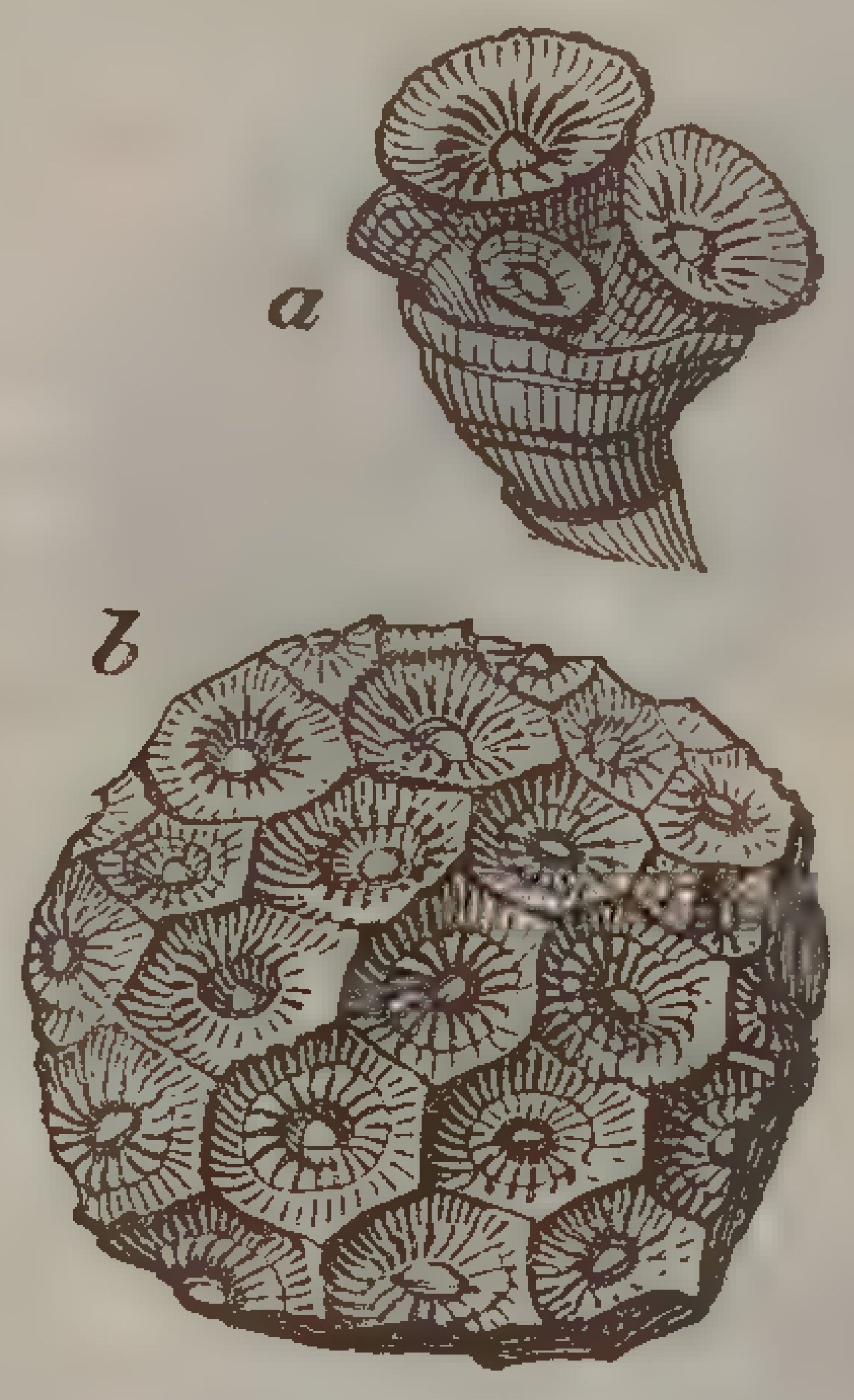
It is not enough, therefore, to say that the primary or more ancient corals are all generically and specifically dissimilar from the secondary, tertiary, and living corals,—for, more than this, they belong to distinct Orders, although often so like in outward form as to have been referred in many cases to living reef-building genera. Hence we must not too confidently draw conclusions from the modern to the paleozoic polyps, respecting climate and the temperature of the waters of the primeval seas, inasmuch as the two groups of zoophytes are constructed on essentially different types. When the great number of the paleozoic and neozoic species is taken into account, it is truly wonderful to find how constant the rule above explained holds good; only one exception having as yet occurred of a quadripartite coral in a neozoic formation (the cretaceous), and one only of the sextuple class (a *Fungia ?*) in paleozoic (Silurian) rocks.

From a great number of lamelliferous corals met with in the Mountain Limestone, two species have been selected, as having a very wide range, extending from the eastern borders of Russia to the British Isles, and being found almost everywhere in each country.

Fig. 516.

Lithostrotion basaltiforme, Phil. sp. (*Lithostrotion striatum*, Fleming; *Astræa basaltiformis*, Conyb. and Phill.) Kendal; Ireland; Russia; Iowa, and westward of the Mississippi, United States. (D. D. Owen.)

Fig. 517.



Lonsdaleia floriformis (Martin, sp.) M. Edwards. (*Lithostrotion floriforme*, Fleming. *Strombodes*.)
a. Young specimen, with buds on the disk.
b. Part of a full-grown compound mass. Bristol, &c.; Russia.

These fossils, together with numerous species of *Zaphrentis*, *Amplexus*, *Cyathophyllum*, *Clisiophyllum*, *Syringopora*, and *Michelinea*[*],

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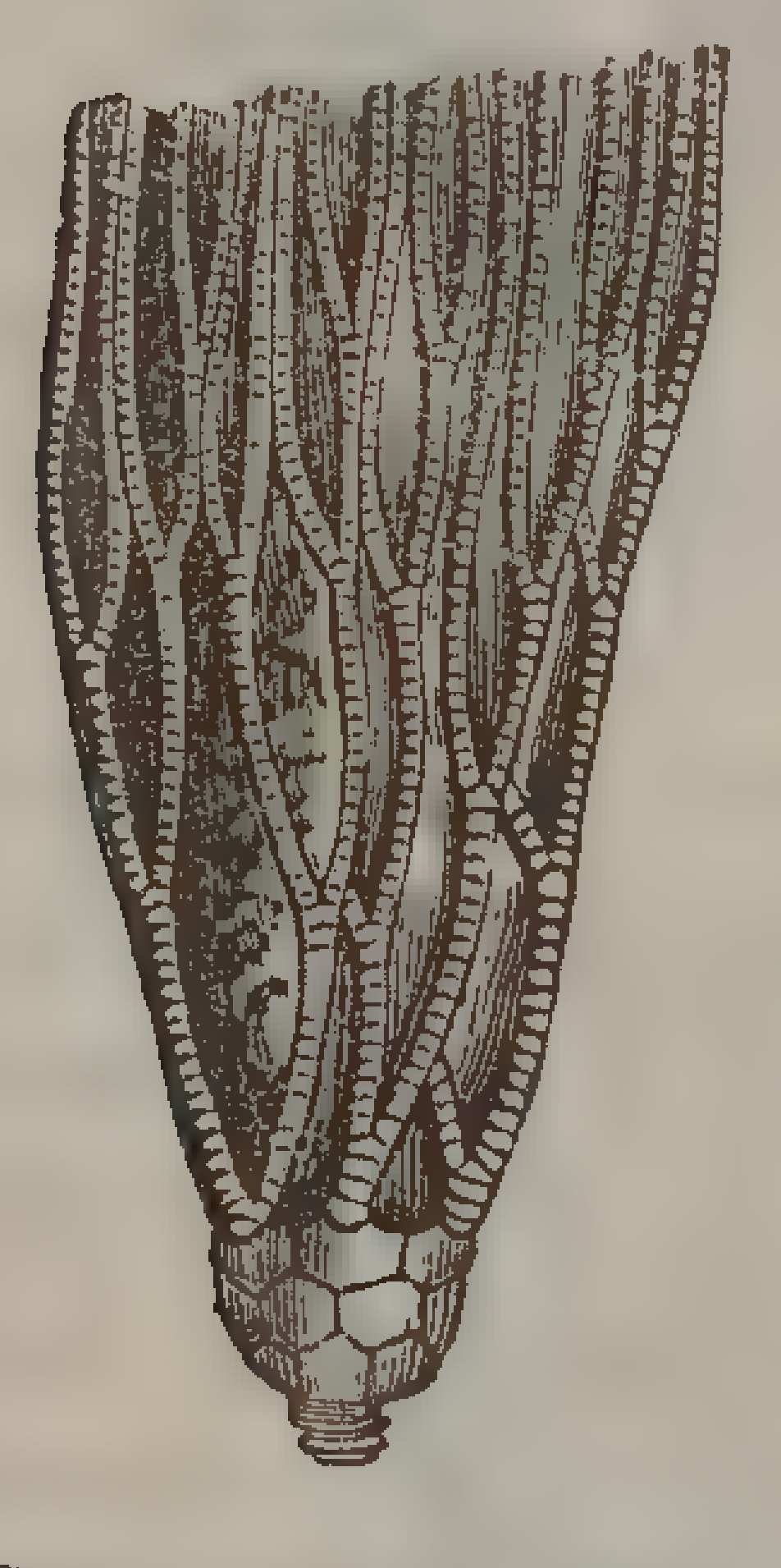
[*] For figures of these corals see Paleontographical Society's Monographs, 1852.

form a group widely different from any that preceded or followed them.

Of the *Bryozoa*, the prevailing forms are *Fenestella* and *Polypora*, and these often form considerable beds. Their net-like fronds are easily recognised.

Crinoidea are also numerous in the Mountain Limestone. (See figs. 518, 519.)

Fig. 518.



Cyathocrinites planus, Miller. Body and arms. Mountain Limestone.

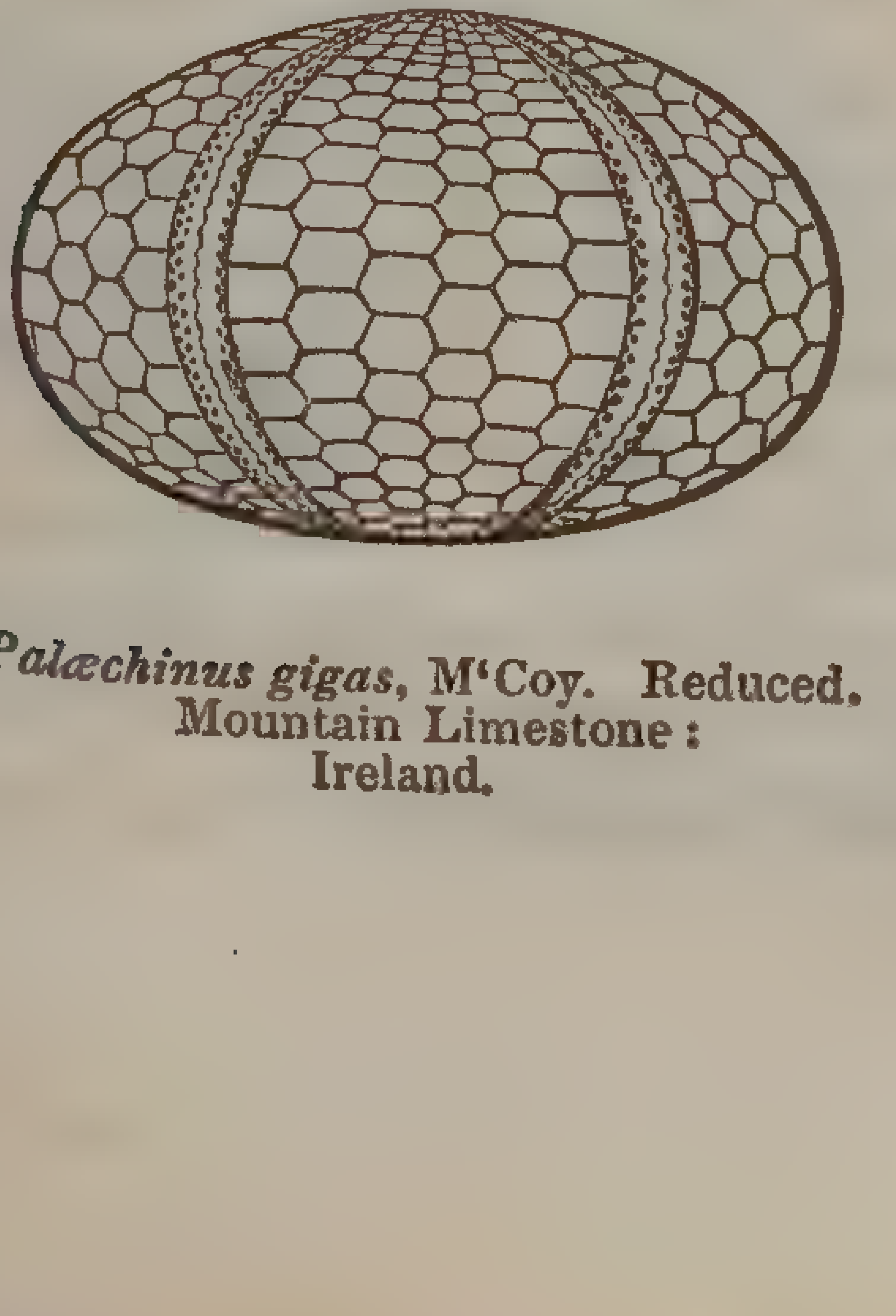
Fig. 519.

Cyathocrinus caryocrinoides, M'Coy.
a. Surface of one of the joints of the stem.
b. Pelvis or body; called also calyx or cup.
c. One of the pelvic plates.

In the greater part of them, the cup or pelvis, fig. 519. *b*, is greatly developed in size in proportion to the arms, although this is not the case in fig. 518. The genera *Poteriocrinus*, *Cyathocrinus*, *Pentremites*, *Actinocrinus*, and *Platycrinus* are all of them characteristic of this formation. Other Echinoderms are rare, a few Sea-Urchins only being known: these have a complex structure, with many more plates on their surface than are seen in the modern genera of the same group. One genus, the *Palæchinus* (fig. 520.), is the analogue of the modern *Echinus*. The other, *Archæocidaris*, represents, in like manner, the *Cidaris* of the present seas.

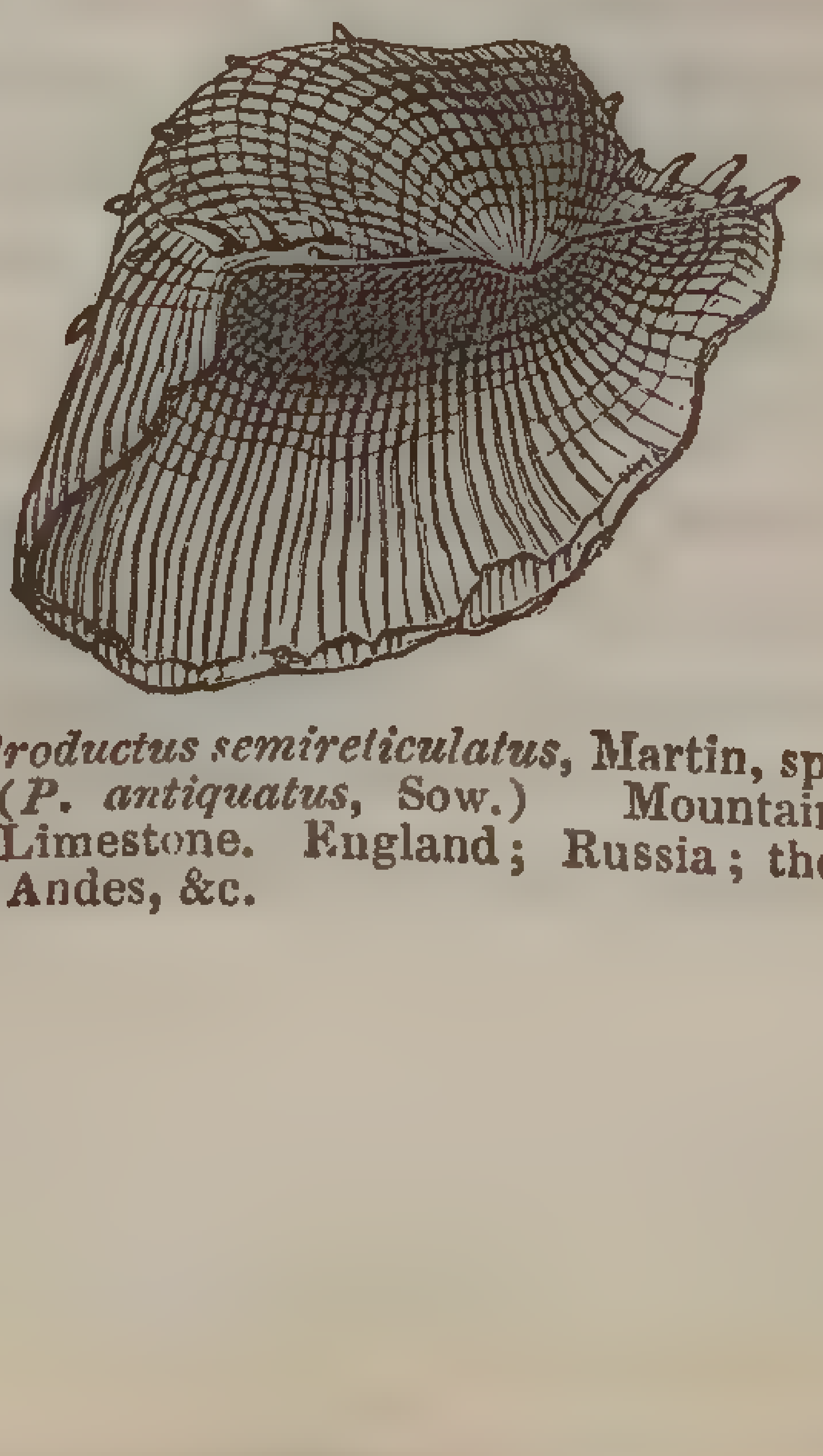
Of Mollusca the *Brachiopoda* (or Palliobranchiates) constitute the larger part, and are not only numerous, but often of large size. Perhaps the most characteristic shells of the formation are large species of *Productus*, such as *P. giganteus*, *P. hemisphæricus*, *P semireticulatus* (fig. 521.), and *P. scabriculus*. Large plaited spirifers, as

Fig. 520.



Palæchinus gigas, M'Coy. Reduced. Mountain Limestone: Ireland.

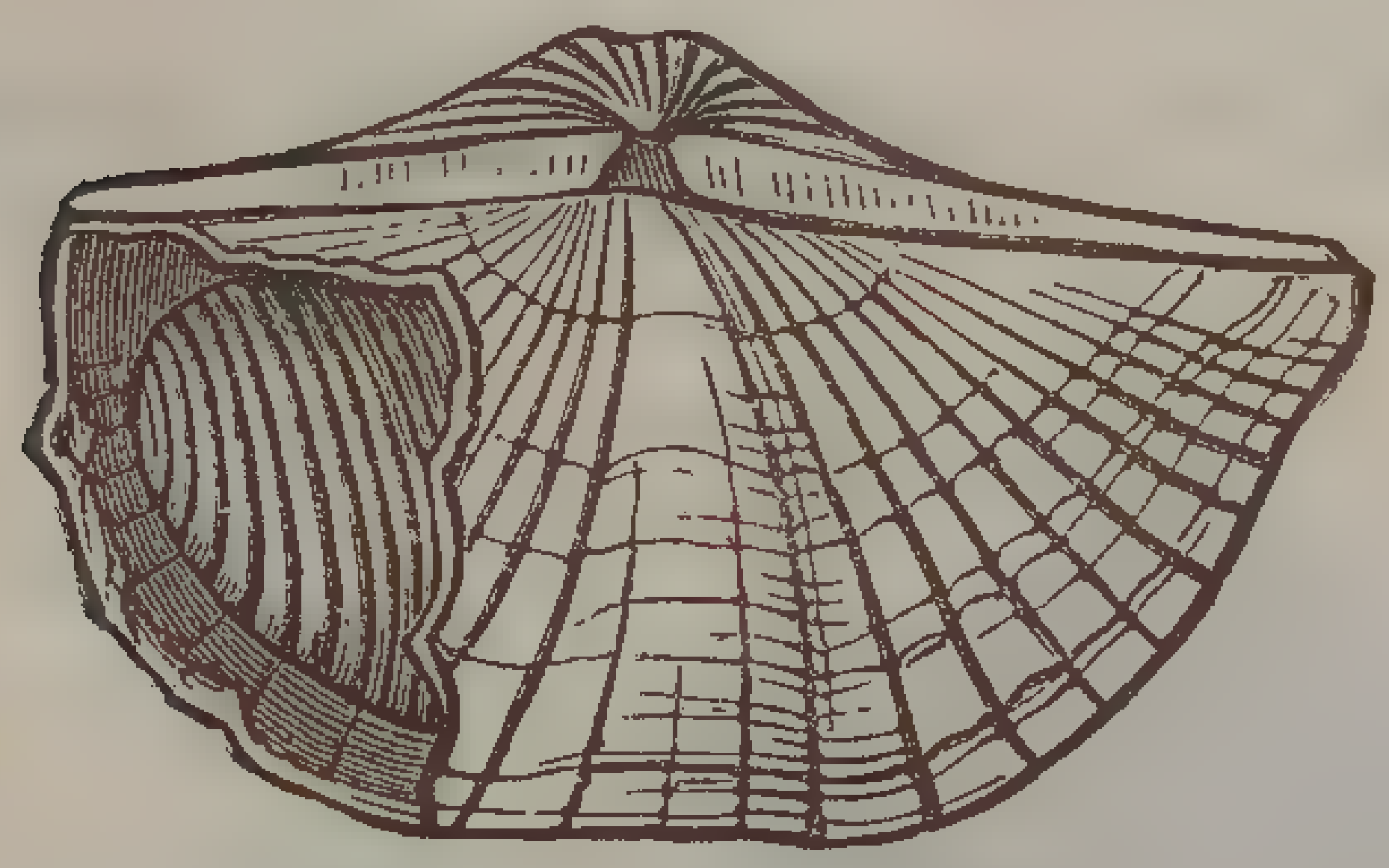
Fig. 521.



Productus semireticulatus, Martin, sp. (*P. antiquatus*, Sow.) Mountain Limestone. England; Russia; the Andes, &c.

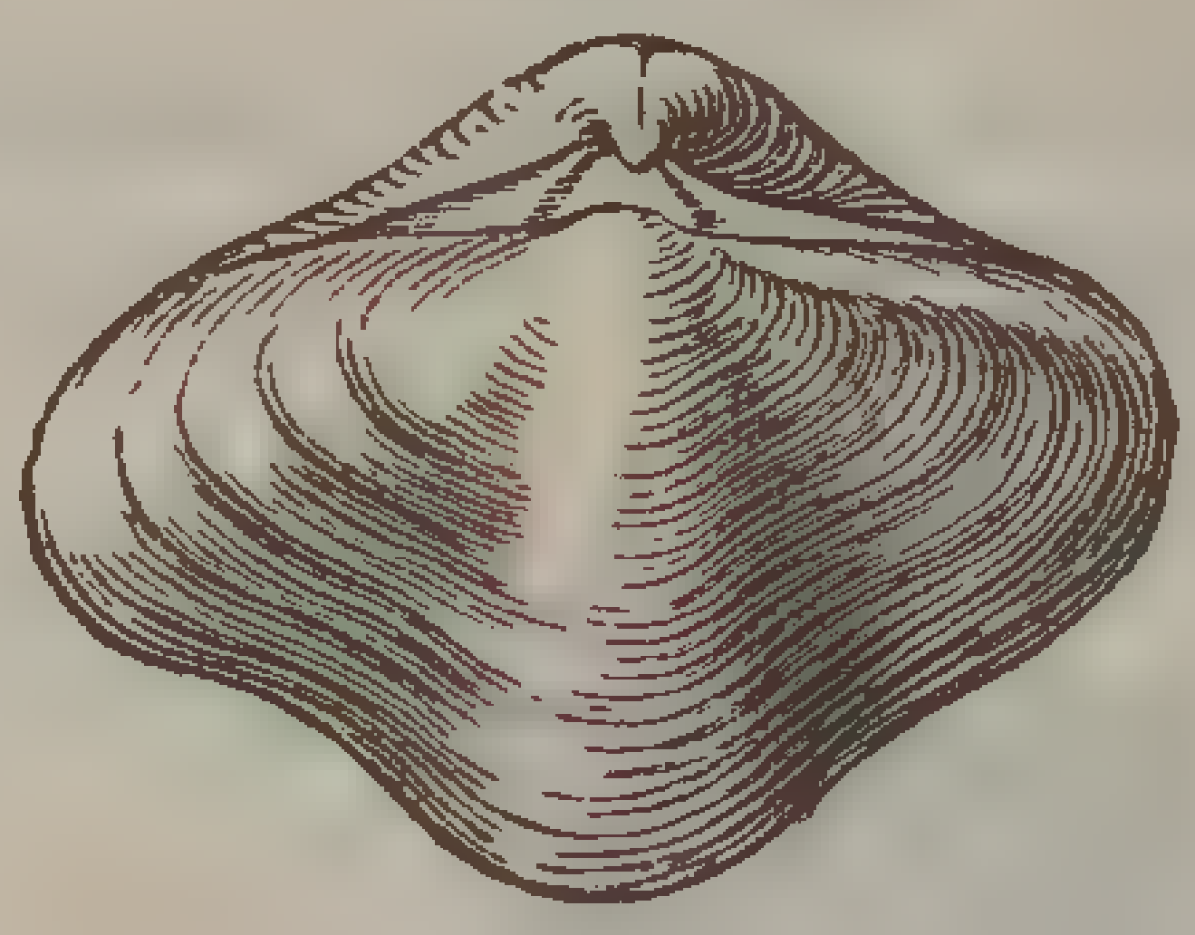
Spirifer striatus, *S. rotundatus*, and *S. trigonalis* (fig. 522.), also abound; and smooth species, such as *Spirifer glaber* (fig. 523.) with its numerous varieties.

Fig. 522.



Spirifer trigonalis, Martin, sp.
Mountain Limestone: Derbyshire, &c.

Fig. 523.



Spirifer glaber, Martin, sp.
Mountain Limestone.

Among the palliobranchiate mollusks *Terebratula hastata* deserves mention, not only for its wide range, but because it often retains the pattern of the original coloured stripes which ornamented the living shell. (See fig. 524.) These coloured bands are also preserved in several lamellibranchiate bivalves, as in *Aviculopecten* (fig. 525.), in which dark stripes alternate with a light ground. In some also of the spiral univalves, the pattern of the original painting is distinctly retained, as in the *Pleurotomaria* (fig. 526.), which displays wavy blotches, resembling the colouring in many recent Trochidæ.

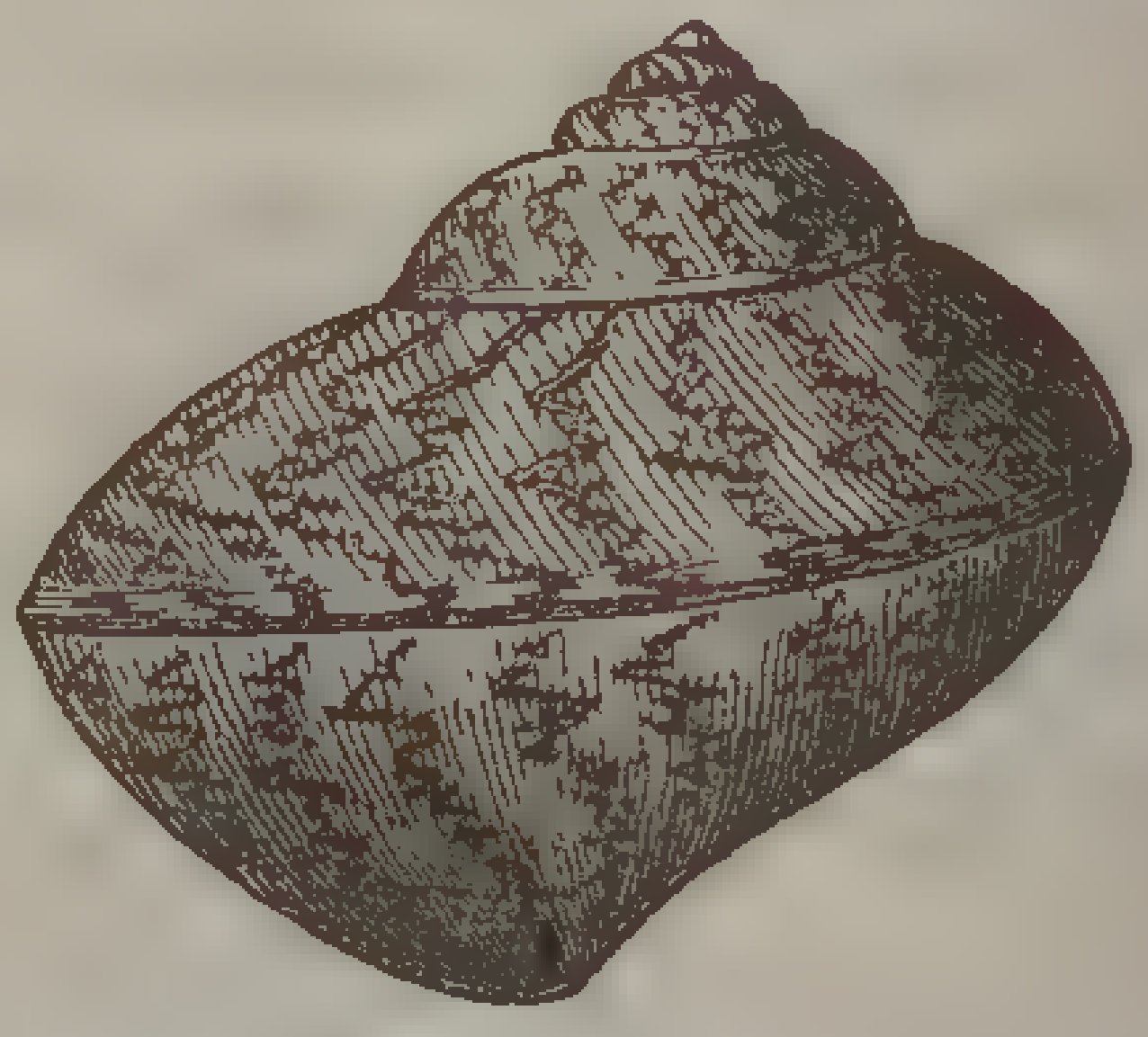
Fig. 524.

Terebratula hastata, Sow., with radiating bands of colour. Mountain Limestone. Derbyshire; Ireland; Russia, &c.

Fig. 525.

Aviculopecten sublobatus, Phill. Mountain Limestone. Derbyshire; Yorkshire.

Fig. 526.



Pleurotomaria carinata, Sow. (*P. flammigera*, Phill.) Mountain Limestone. Derbyshire, &c.

The mere fact that shells of such high antiquity should have preserved the patterns of their colouring is striking and unexpected; but Prof. E. Forbes has deduced from it an important geological conclusion. He infers that the depth of the primeval seas in which the Mountain Limestone was formed did not exceed 50 fathoms. To this opinion he is led by observing that in the existing seas the testacea which have colours and well defined patterns rarely inhabit greater depths than 50 fathoms; and the greater number are found where there is most light in very shallow water, not more than two fathoms deep. There are even examples in the British seas of testacea which are always white or colourless when taken from below 100 fathoms; and yet individuals of the same species, if taken from shallower zones, are vividly striped or banded.

This information, derived from the colour of the shells, is the more welcome, because the Radiata, Articulata, and Mollusca of the Carboniferous period belong almost entirely to genera no longer found in the living creation, and respecting the habits of which we can only hazard conjectures.

Some few of the carboniferous mollusca, such as *Avicula*, *Nucula*, *Solemya*, and *Lithodomus*, belong no doubt to existing genera; but the majority, though often referred to living types, such as *Isocardia*, *Turritella*, and *Buccinum*, belong really to forms which appear to have become extinct at the close of the paleozoic epoch. *Euomphalus* is a characteristic univalve shell of this period. In the interior it is often divided into chambers (fig. 527. *d*), the septa or partitions not being perforated as in foraminiferous shells, or in those having siphuncles, like the Nautilus. The animal appears to have retreated at different periods of its growth from the internal cavity previously formed, and to have closed all communication with it by a septum. The number of chambers is irregular, and they are generally wanting in the innermost whorl. The animal of the recent *Turritella communis* partitions off in like manner as it advances in age a part of its spire, forming a shelly septum.

Fig. 527.

Euomphalus pentagulatus, Sowerby. Mountain Limestone.
a. Upper side; *b*. lower, or umbilical side; *c*. view showing mouth, which is less pentagonal in older individuals; *d*. view of polished section, showing internal chambers.

Fig. 528.

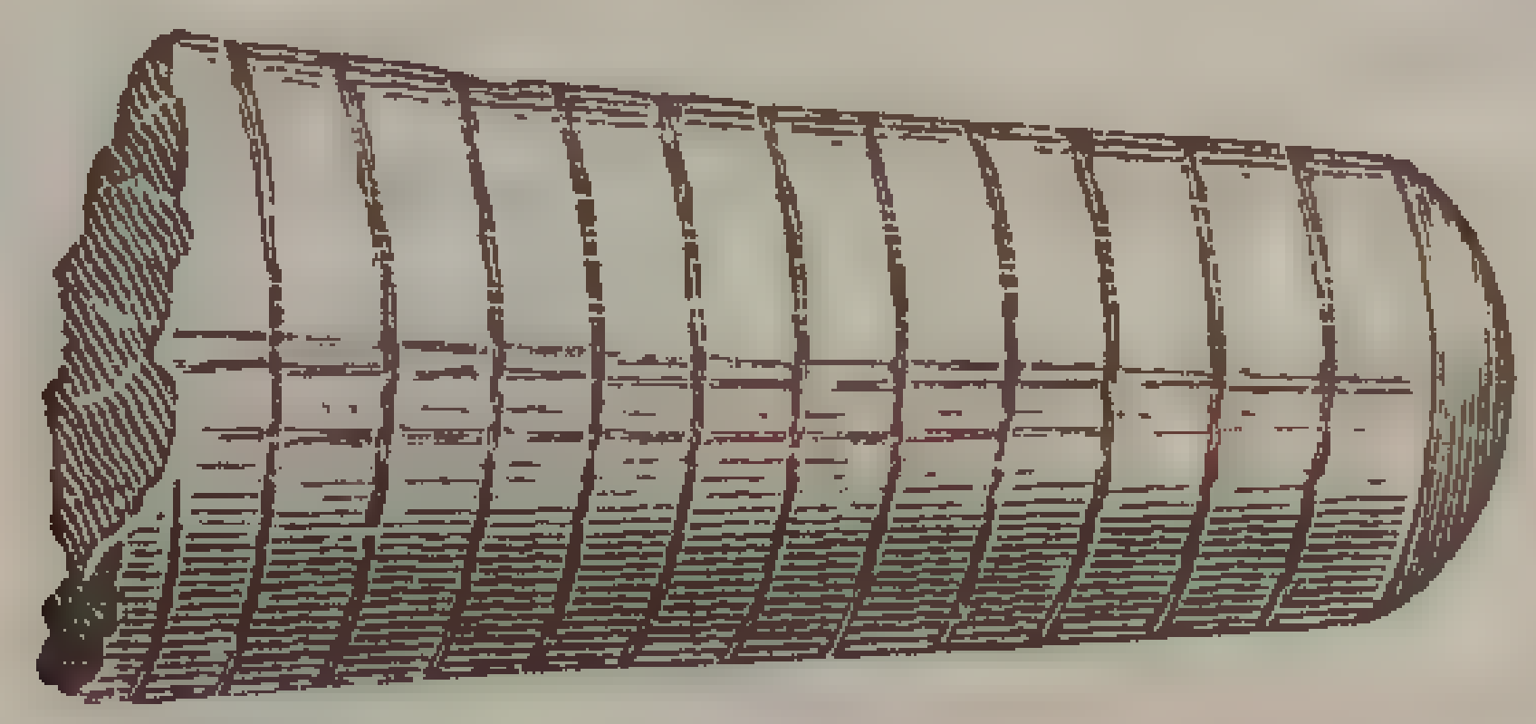
Bellerophon costatus, Sow. Mountain Limestone.

Nearly 20 species of the genus *Bellerophon* (see fig. 528.), a shell without chambers like the living Argonaut, occur in the Mountain Limestone. The genus is not met with in strata of later date. It is most generally regarded as belonging to the

Heteropoda, and allied to the Glass-Shell, *Carinaria;* but by some few it is thought to be a simple form of Cephalopod.

The carboniferous Cephalopoda do not depart so widely from the living type (the Nautilus), as do the more ancient Silurian representatives of the same order; yet they offer some remarkable forms scarcely known in strata newer than the coal. Among these is *Orthoceras*, a siphuncled and chambered shell, like a *Nautilus* uncoiled and straightened (fig. 529.). Some species of this genus are several feet long. The *Goniatite* is another genus, nearly allied to the *Ammonite*, from which it differs in having the lobes of the septa free from lateral denticulations, or crenatures; so that the outline of these is continuous and uninterrupted.

Fig. 529.

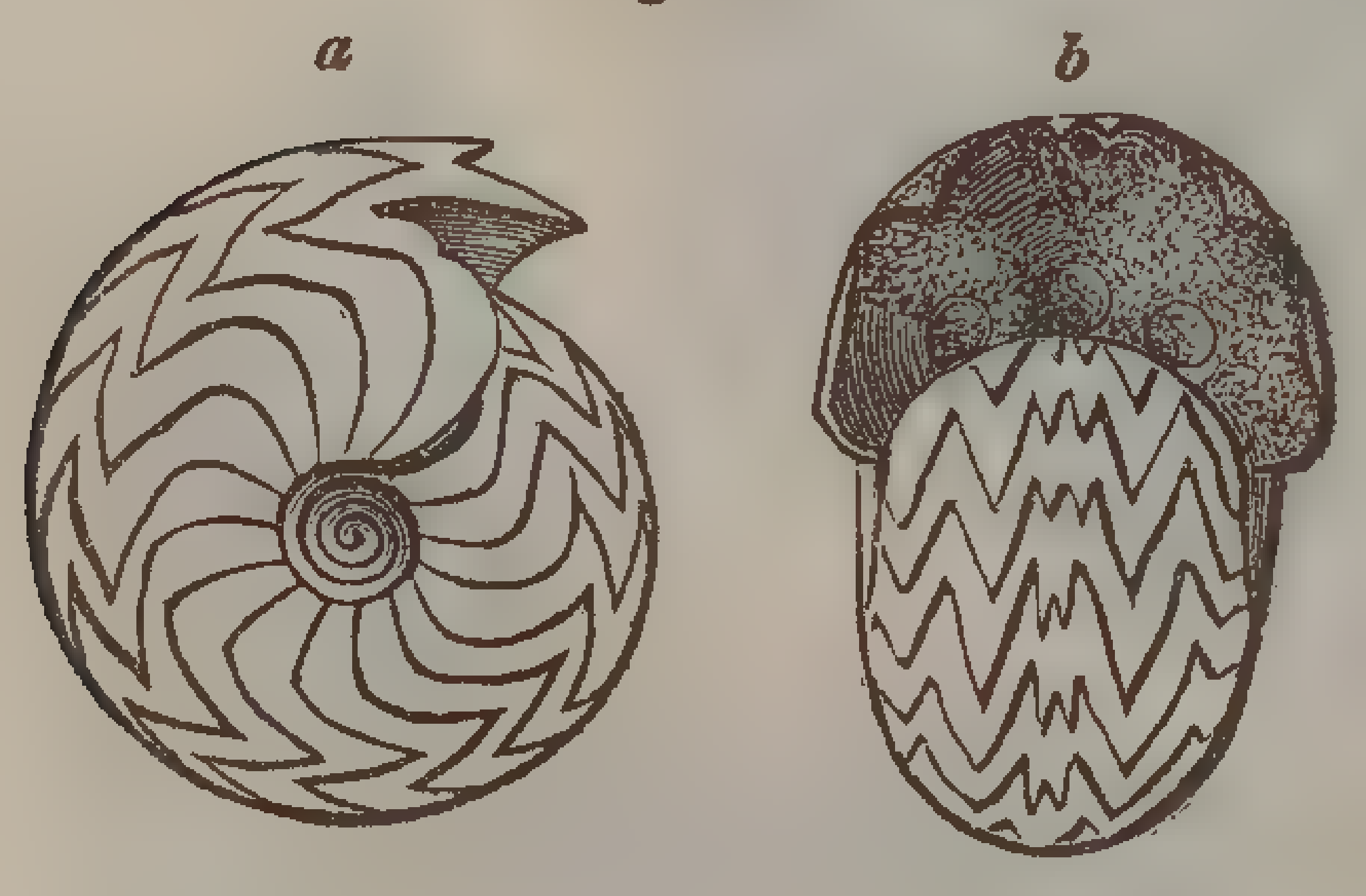


Portion of *Orthoceras laterale*, Phillips. Mountain Limestone.

The species represented in fig. 530. is found in almost all localities, and presents the zigzag character of the septal lobes in perfection.

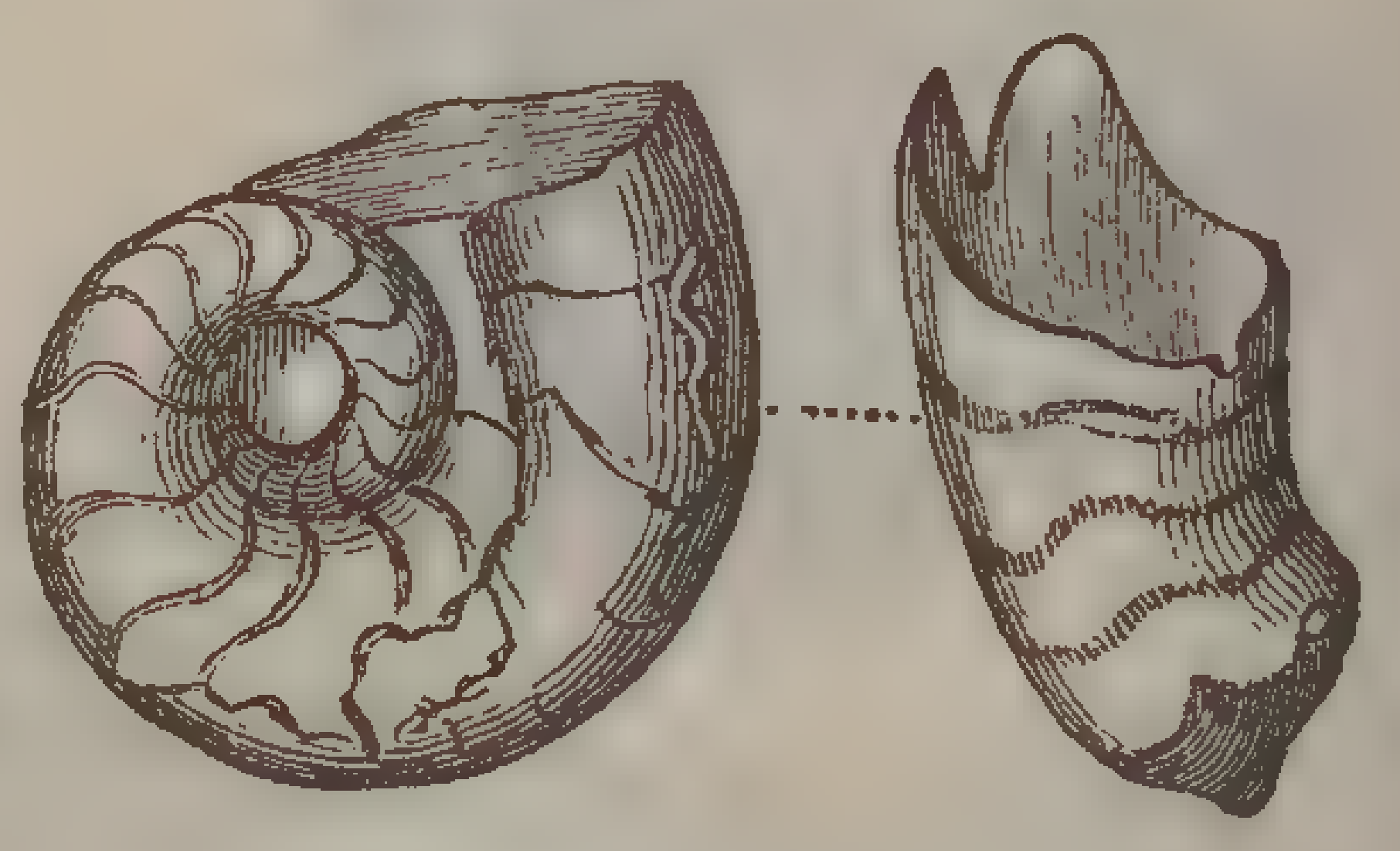
In another species (fig. 531.), the septa are but slightly waved, and so approach nearer to the form of those of the Nautilus. The dorsal position of the siphuncle, however, clearly distinguishes the Goniatite from the Nautilus, and proves it to have belonged to the family of the Ammonites, from which, indeed, some authors do not believe it to be generically distinct.

Fig. 530.



Goniatites crenistria, Phill. Mountain Limestone. N. America; Britain; Germany, &c.
a. Lateral view.
b. Front view, showing the mouth.

Fig. 531.

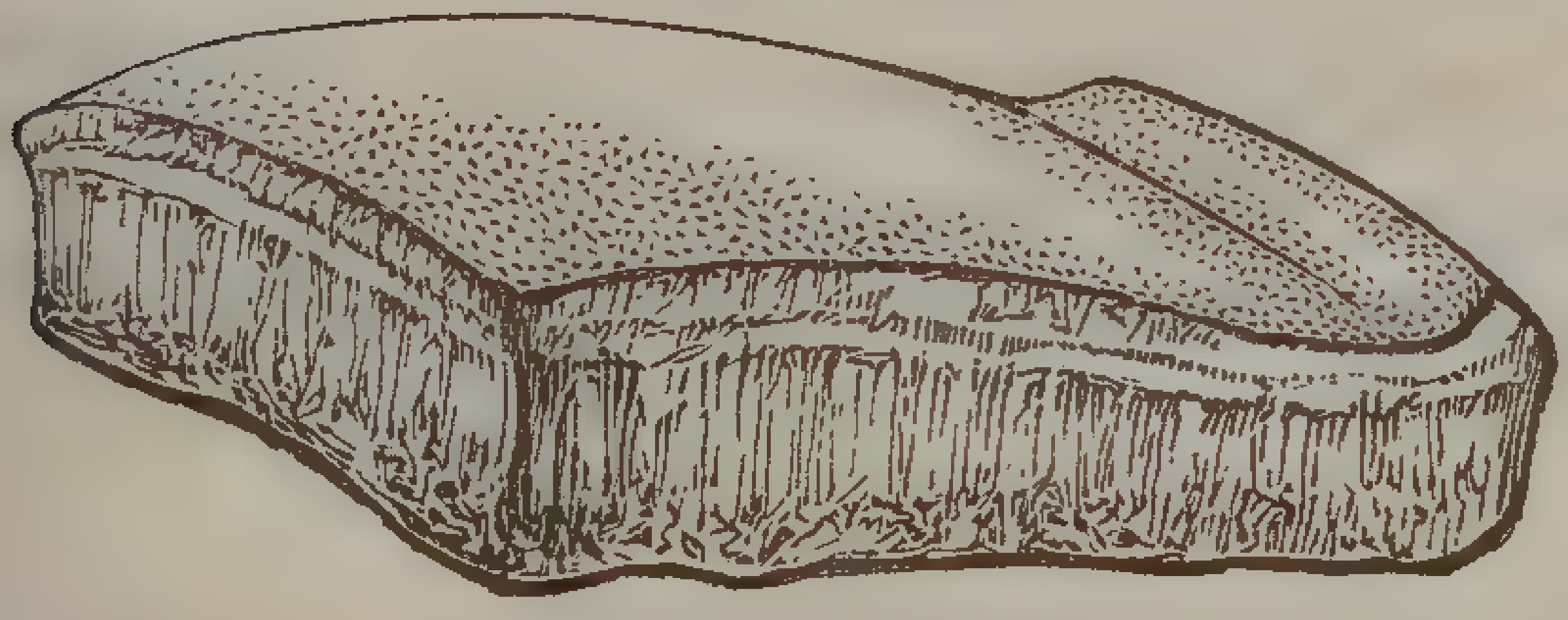


Goniatites evolutus, Phillips. Mountain Limestone. Yorkshire.

Fossil fish. — The distribution of these is singularly partial; so much so, that M. de Koninck of Liege, the eminent paleontologist, once stated to me that, in making his extensive collection of the fossils of the Mountain Limestone of Belgium, he had found no more than four or five examples of the bones or teeth of fishes. Judging from Belgian data, he might have concluded that this class of vertebrata was of extreme rarity in the carboniferous seas; whereas the investigation of other countries has led to quite a different result.

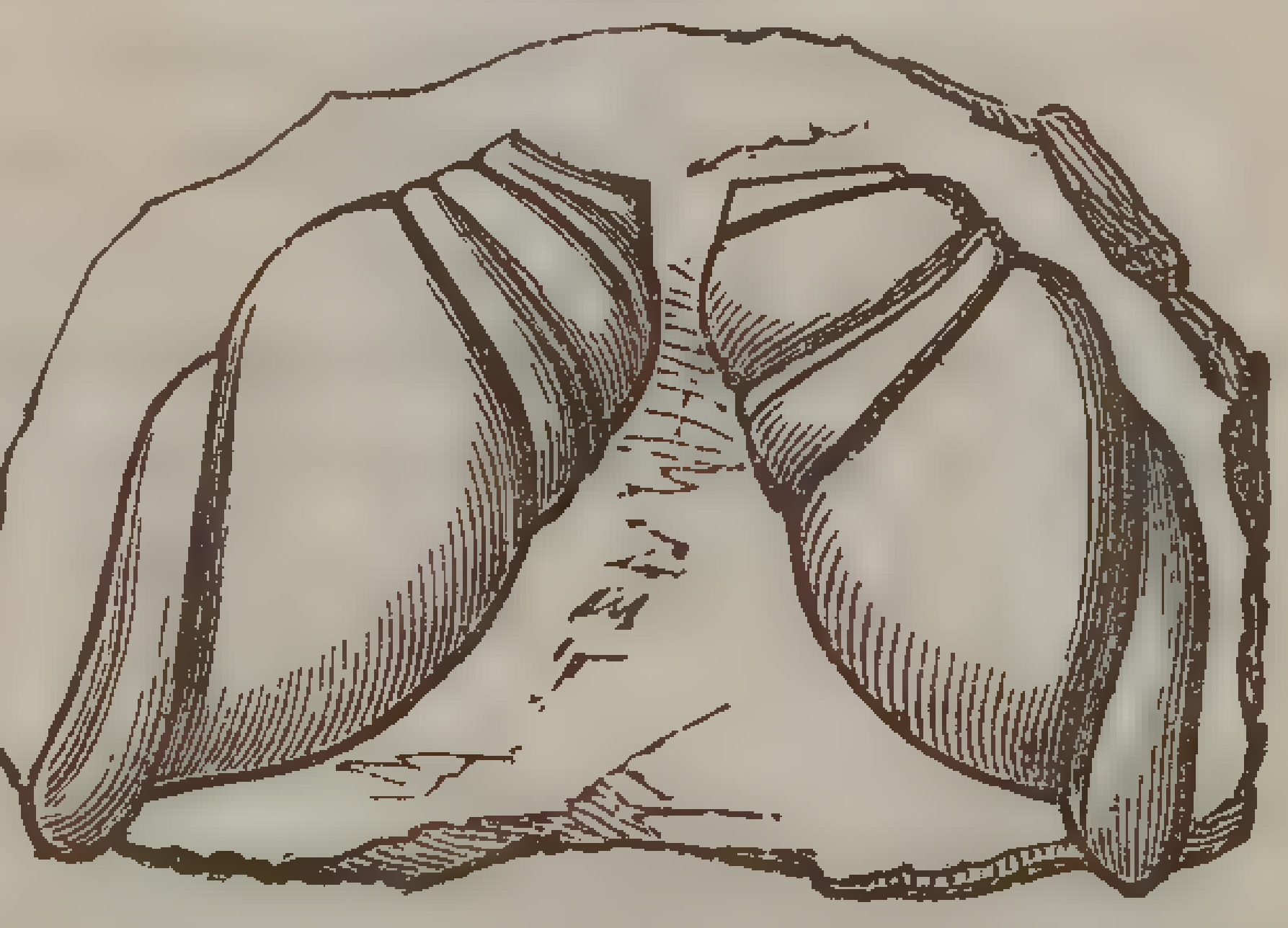
Thus, near Clifton, on the Avon, there is a celebrated "bone-bed," almost entirely made up of ichthyolites; and the same may be said of the "fish-beds" of Armagh, in Ireland. They consist chiefly of the teeth of fishes of the Placoid order, nearly all of them rolled as if drifted from a distance. Some teeth are sharp and pointed, as in ordinary sharks, of which the genus *Cladodus* affords an illustration; but the majority, as in *Psammodus* and *Cochliodus*, are, like the teeth of the Cestracion of Port Jackson (see above, fig. 288., p. 250.), massive palatal teeth fitted for grinding. (See figs. 532, 533.)

Fig. 532.



Psammodus porosus, Agas. Bone-bed, Mountain Limestone. Bristol; Armagh.

Fig. 533.



Cochliodus contortus, Agas. Bone-bed, Mountain Limestone. Bristol; Armagh.

There are upwards of 70 other species of fish-remains known in the Mountain Limestone of the British Islands. The defensive fin-bones of these creatures are not unfrequent at Armagh and Bristol; those known as *Oracanthus* are often of a very large size. Ganoid fish, such as *Holoptychius*, also occur; but these are far less numerous. The great *Megalichthys Hibberti* appears to range from the Upper Coal-measures to the lowest Carboniferous strata.

Foraminifera.—This somewhat important group of the lower animals, which is represented so fully at later epochs by the Nummulites and their numerous minute allies, appears in the Mountain Limestone to be restricted to a very few species, the individuals, however, of which are vastly numerous. *Textularia*, *Nodosaria*, *Endothyra*, and *Fusulina* (fig. 534.), have been recognised. The first two genera are common to this and all the after periods; the third has already appeared in the Upper Silurian, but is not known above the Carboniferous; the fourth (fig. 534.) is peculiar to the Mountain Limestone, and is characteristic of the formation in the United States, Russia, and Asia Minor.

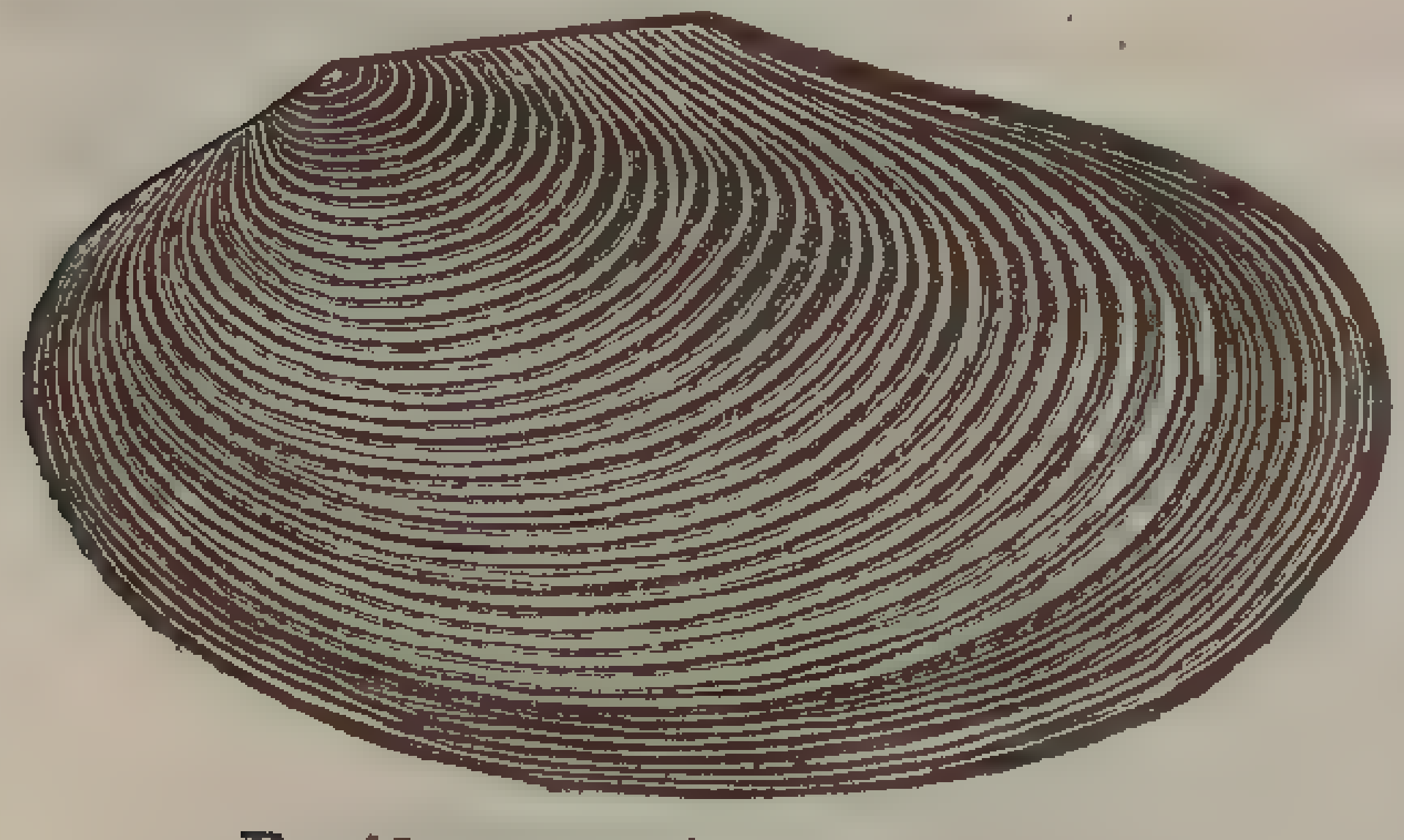
Fig. 534.

Fusulina cylindrica, D'Orb. Magnified 3 diam. Mountain Limestone.

STRATA CONTEMPORANEOUS WITH THE MOUNTAIN LIMESTONE.

In countries where limestone does not form the principal part of the Lower Carboniferous series, this formation assumes a very different character, as in the Rhenish Provinces of Prussia, and in the Hartz. The slates and sandstones called Kiesel-schiefer and Younger Greywacke (Jungere grauwacke) by the Germans, were ormerly referred to the Devonian group, but are now ascertained to belong to the "Lower Carboniferous." The prevailing shell which characterizes the carbonaceous schists of this series, both on the Continent and in England, is *Posidonomya Becheri* (fig. 535.). Some well-known mountain-limestone species, such as *Goniatites crenistria* (see fig. 530.) and *G. reticulatus*, also occur in the Hartz. In the associated sandstones of the same region, fossil plants, such as *Lepidodendron* and the allied genus *Saginaria*, are common; also *Knorria*, *Calamites Suckovii*, and *C. transitionis* Göpp., some peculiar, others specifically identical with ordinary coal-measure fossils. The true geological position of these rocks in the Hartz was first determined by MM. Murchison and Sedgwick in 1840.*

Fig. 535.



Posidonomya Becheri, Gold.
Lower Carboniferous.

CARBONIFEROUS LIMESTONE IN NORTH AMERICA.

The coal-measures of Nova Scotia have been described (p. 379.). The lower division contains, besides large stratified masses of gypsum, some bands of marine limestone almost entirely made up of encrinites, and, in some places, containing shells of genera common to the mountain limestone of Europe.

In the United States the carboniferous limestone underlies the productive coal-measures; and, although very inconspicuous on the margin of the Alleghany or Great Appalachian coal-field in Pennsylvania, it expands in Virginia and Tenessee. Its still greater extent and importance in the Western or Mississippi coal-fields, in Kentucky, Indiana, Iowa, Missouri, and other western states, has been well shown by Dr. D. D. Owen. In those regions† it is about 400 feet thick, and abounds, as in Europe, in shells of the genera *Productus* and *Spirifer*, with *Pentremites* and other crinoids and corals. Among the latter, *Lithostrotion basaltiforme* or *striatum* (fig. 516. p. 408.), or a closely-allied species, is common.

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* Trans. Geol. Soc. London, 2nd series, vol. vi. p. 228.

† Owen's Geol. Survey of Wisconsin, &c. 1852.

CHAPTER XXVI.

OLD RED SANDSTONE, OR DEVONIAN GROUP.

Old Red Sandstone of the Borders of Wales—Of Scotland and the South of Ireland —Fossil reptile and foot-tracks at Elgin—Fossil Devonian plants at Kilkenny— Ichthyolites of Clashbinnie—Fossil fish, crustaceans, &c., of Caithness and Forfarshire—Distinct lithological type of Old Red in Devon and Cornwall— Term Devonian—Organic remains of intermediate character between those of the Carboniferous and Silurian systems—Devonian series of England and the Continent—Upper Devonian rocks and fossils—Middle—Lower—Old Red Sandstone of Russia—Devonian Strata of the United States—Coral-reefs at the Falls of the Ohio.

It has been already shown in the section (p. 334.), that the carboniferous strata are surmounted by a system called "The New Red," and underlaid by another termed the "Old Red Sandstone." The last-mentioned group acquired this name because in Herefordshire and Scotland, where it was originally studied, it consisted chiefly of red sandstone, shale, and conglomerate. It was afterwards termed "Devonian," for reasons which will be explained in the sequel. For many years it was regarded as very barren of organic remains; and such is undoubtedly its character over very wide areas where calcareous matter is wanting, and where its colour is determined by the red oxide of iron.

"Old Red" in Herefordshire, &c.—In Herefordshire, Worcestershire, Shropshire, and South Wales, this formation attains a great thickness, sometimes between 8,000 and 10,000 feet. In these regions, it has been subdivided into

1st. Conglomerate, passing downwards into chocolate-red and green sandstone and marl.

2nd. Marl and cornstone,—red and green argillaceous spotted marls, with irregular courses of impure concretionary limestone, provincially called Cornstone, and some beds of white sandstone. In the cornstones, and in those flagstones and marls through which calcareous matter is most diffused, some remains of fishes of the genera *Onchus* and *Cephalaspis* occur. Several specimens of the latter have been traced to the lowest beds of the "Old Red," in May Hill, in Gloucestershire, by Sir R. Murchison and Mr. Strickland.*

Old Red Sandstone of Scotland and Ireland.—South of the Grampians, in Forfarshire, Kincardineshire, and Fife, the Old Red Sandstone may be divided into three groups.

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* Murchison's Siluria, p. 245.

A. Yellow sandstone, with some bands of white sandstone.

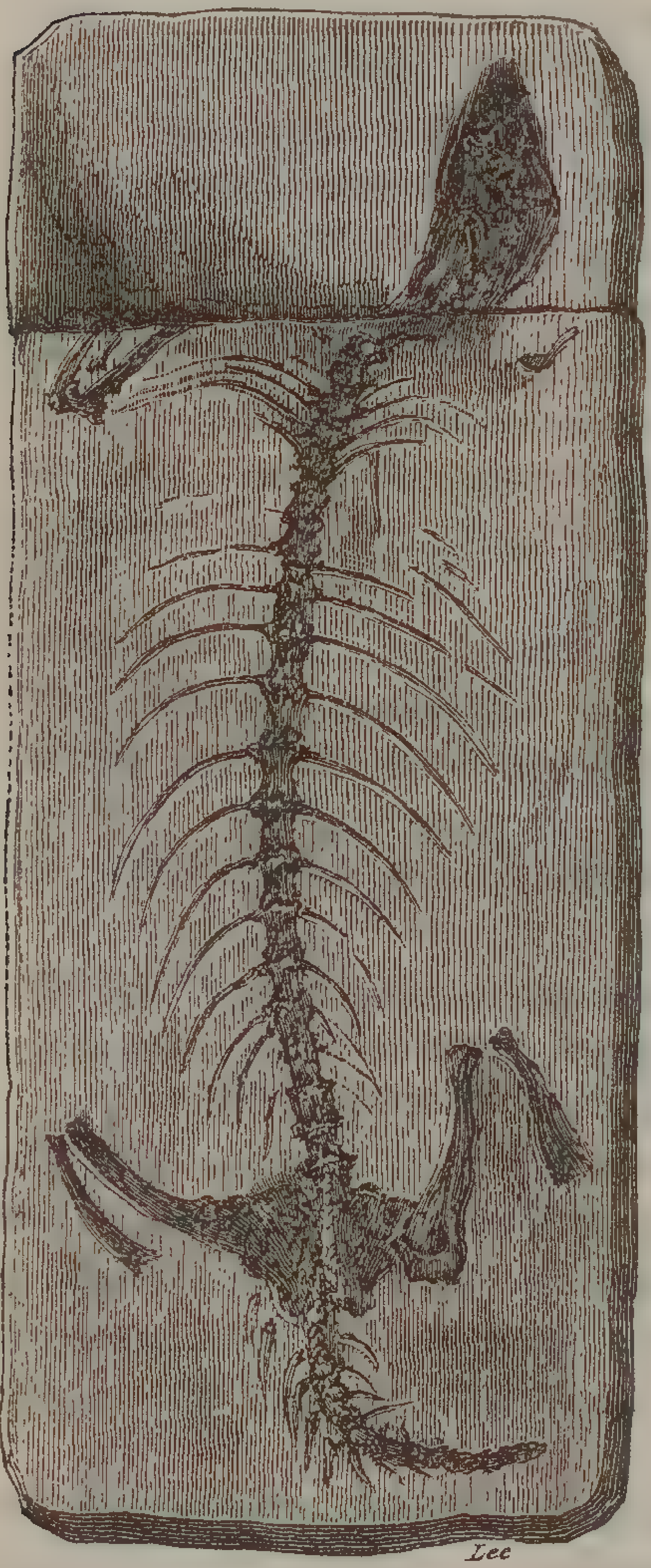
B. Red shale, sandstone with cornstone, and at the base a conglomerate (Nos. 1, 2, & 3. Section, p. 48.).

C. Roofing and paving stone, highly micaceous, and containing a slight admixture of carbonate of lime (No. 4., p. 48.).

The upper member, or yellow sandstone, A, is seen at Dura Den, near Cupar, in Fife, immediately underlying the coal. It consists of a yellow sandstone in which fish of the genera *Pterichthys* (for genus see fig. 550.), *Pamphractus*, *Glyptopomus*, *Holoptychius*, and others abound.

On the south side of the Moray Firth, near Elgin, certain yellow and white sandstones were classed long since by Professor Sedgwick and Sir R. Murchison as the uppermost beds of the "Old Red;" and they are generally regarded as the equivalent of the Yellow Sandstone of Fife above alluded to. They contain large rhomboidal scales of a fish called by Agassiz *Stagonolepis Robertsoni*, and referred by him to the Dipterian family. This family, observes Mr. Hugh Miller, is emphatically characteristic of the Old Red Sandstone. The scales of this *Stagonolepis*, the only parts of the species yet known, are so like those of *Glyptopomus* in form and pattern that they may possibly prove to be referable to the same genus. The *Glyptopomus*, as we have seen, is found in the yellow sandstone of Dura Den in Fife, and the genus has not hitherto been met with in any formation except the Devonian.

Fig. 536.



Telerpeton Elginense. (Mantell.)
Natural size.
Reptile in the Old Red Sandstone, from near Elgin, Morayshire.

The light-coloured sandstone of Morayshire passes down into a conformable series of strata, which are full of undoubted "Old Red" fossils. I have dwelt thus particularly on the age of this rock, because it has yielded recently (1851) the bones of a reptile, the first and only memorials of that class yet discovered in a stratum of such high antiquity. This fossil was obtained by Mr. Patrick Duff, author of a "Sketch of the Geology of Morayshire," from a quarry at Cummingstone, near Elgin. The skeleton represented in the annexed figure (fig. 536.), is $4\frac{1}{2}$ inches in length, but part of the tail is concealed in the rock; and, if the whole were visible, it might be more than 6 inches long.

The matrix is a fine-grained whitish sandstone, with a cement of carbonate of lime. Although almost all the bones except those of the skull have decomposed, their natural position can still be seen. Nearly perfect casts of their form were taken by Dr. Mantell from the hollow moulds which they have left in the rock.

Slight indications are visible of minute conical teeth. Of ribs there are twenty-four pairs, very short and slender. The pelvis is placed after the twenty-fourth vertebra, precisely as in the living Iguana. On the whole, Dr. Mantell inferred that the animal possessed many Lacertian characters blended with those of the Batrachians. He was unable to decide whether it was a small terrestrial lizard, or a freshwater Batrachian, resembling the Tritons and aquatic Salamanders.

Although this fossil is the most ancient quadruped of which any osseous remains have yet been brought to light, it seems not to have been the only one then existing in that region, for Captain Brickenden observed, in 1850, on a slab of sandstone from the same quarry at Cummingstone, a continuous series of no less than thirty-four footprints of a quadruped. A small part of this track, the course of which is supposed to have been from A to B, is represented in the annexed cut (fig. 537.). The footprints are in pairs, forming two parallel rows; the hind foot being one inch in diameter and larger than the fore foot in the proportion of 4 to 3. The stride must have been about 4 inches. The impressions resemble those left by a tortoise walking on sand; and, if this be the true interpretation of the trail, they are the only indications as yet known of a chelonian more ancient than the trias.

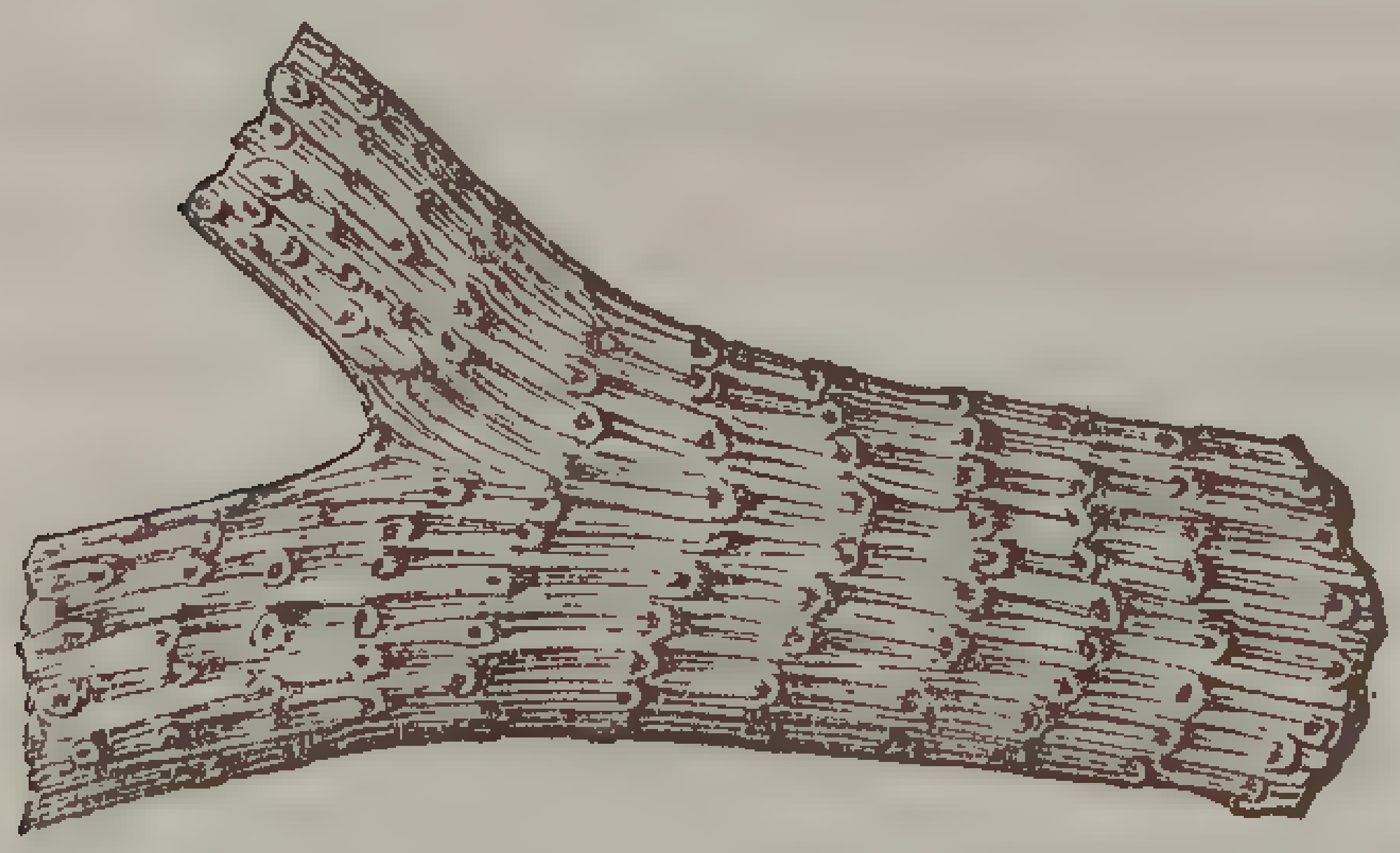
Fig. 537.

Scale one-sixth the original size.
Part of the trail of a (Chelonian ?) quadruped from the Old Red Sandstone of Cummingstone, near Elgin, Morayshire. — Captain Brickenden.

I have already alluded (p. 404.) to trails referred by American geologists to several species of air-breathing reptiles, and discovered on the eastern flank of the Alleghany range, in Pennsylvania, in a red shale, so ancient that a question has arisen whether the rock should be classed as the lowest member of the carboniferous, as Professor H. D. Rogers conceives, or as the uppermost Devonian, as some have contended (see p. 404.). They at least demonstrate that certain quadrupeds, of larger size than any of the bones that have been found in carboniferous rocks, existed at the time when the ancient Red Shale, usually termed in the United States "infra-carboniferous," was in the course of deposition.

In Ireland the upper beds of the Old Red, or yellow sandstone of Kilkenny, contain fish of the genera *Coccosteus* and *Dendrodus*, characteristic forms of this period, together with plants specifically distinct from any known in the coal-measures, but referable to the genera found in them; as, for example, *Lepidodendron* and *Cyclopteris* (see figs. 538. and 539.). The stems of the latter have, in some specimens, broad bases of attachment, and may therefore have been tree-ferns.

Fig. 538.



Stem of *Lepidodendron*, so compressed as to destroy the quincunx arrangement of the scars. Upper Devonian, Kilkenny.

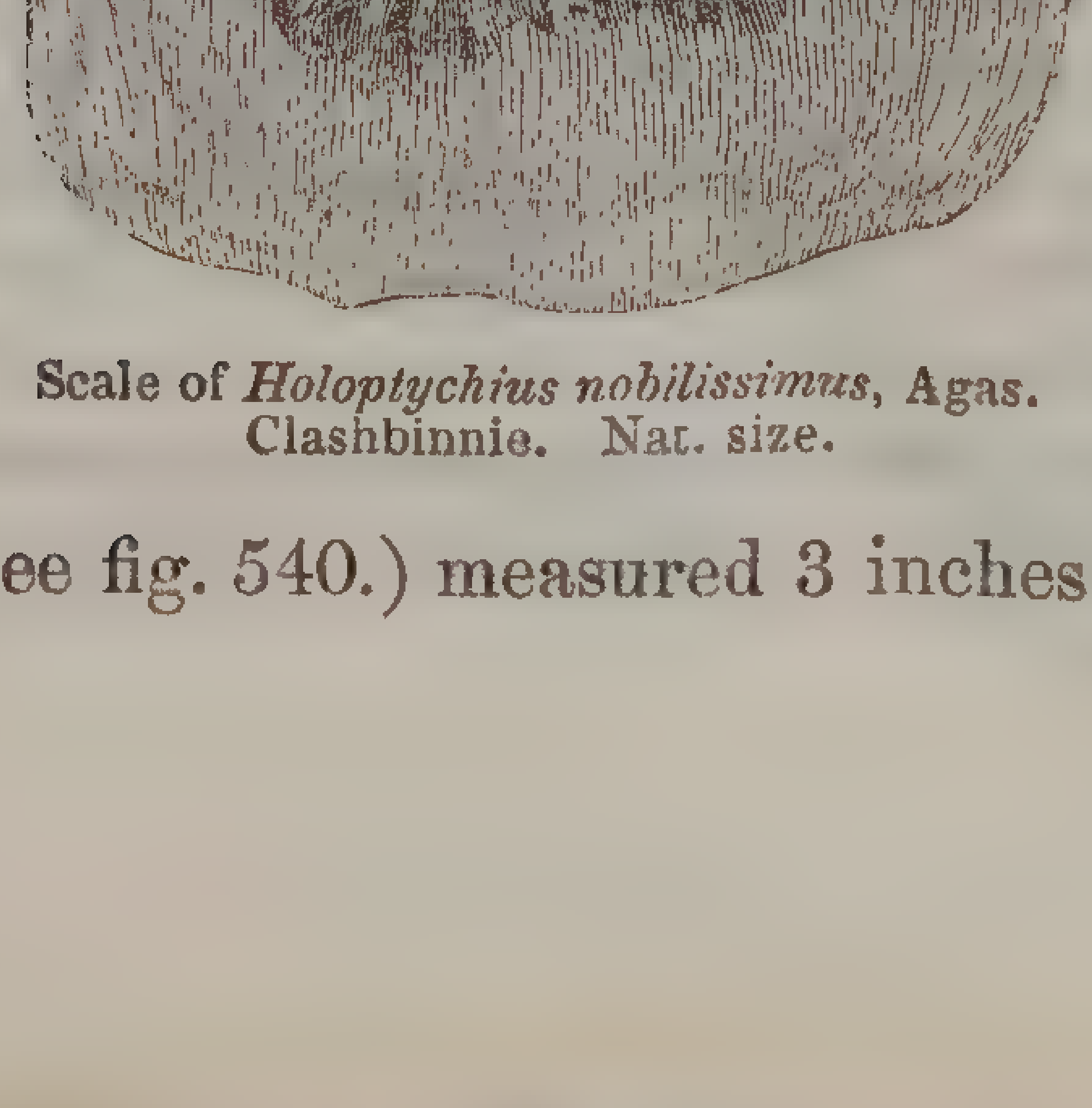
Fig. 539.

Cyclopteris Hibernica, Forbes. Upper Devonian, Kilkenny.

In the same strata shells having the form of the genus *Anodon*, and which probably belonged to freshwater testacea, occur. Some geologists, it is true, still doubt whether these beds ought not rather to be classed as the lowest beds of the carboniferous series, together with the yellow sandstone of Mr. Griffiths (see p. 362.); but the associated ichthyolites and the distinct specific character of the plants, seem to favour the opinion above expressed.

B. (*Table*, p. 416.)—We come next to the middle division of the "Old Red," as exhibited south of the Grampians, and consisting of—1st, red shale and sandstone, with some cornstone, occupying the Valley of Strathmore, in its course from Stonehaven to the Firth of Clyde; and, 2ndly, of a conglomerate, seen both at the foot of the Grampians, and on the flanks of the Sidlaw Hills, as shown in the section at p. 48., Nos. 1, 2, and 3. In the uppermost part of the division No. 1., or in the beds which, in Fife, underlie the yellow sandstone, the scales of a large ganoid fish, of the genus *Holoptychius*, were first observed by Dr. Fleming at Clashbinnie, near Perth, and an entire specimen, more than 2 feet in length, was afterwards found by Mr. Noble. Some of these scales (see fig. 540.) measured 3 inches in length, and 2½ in breadth.

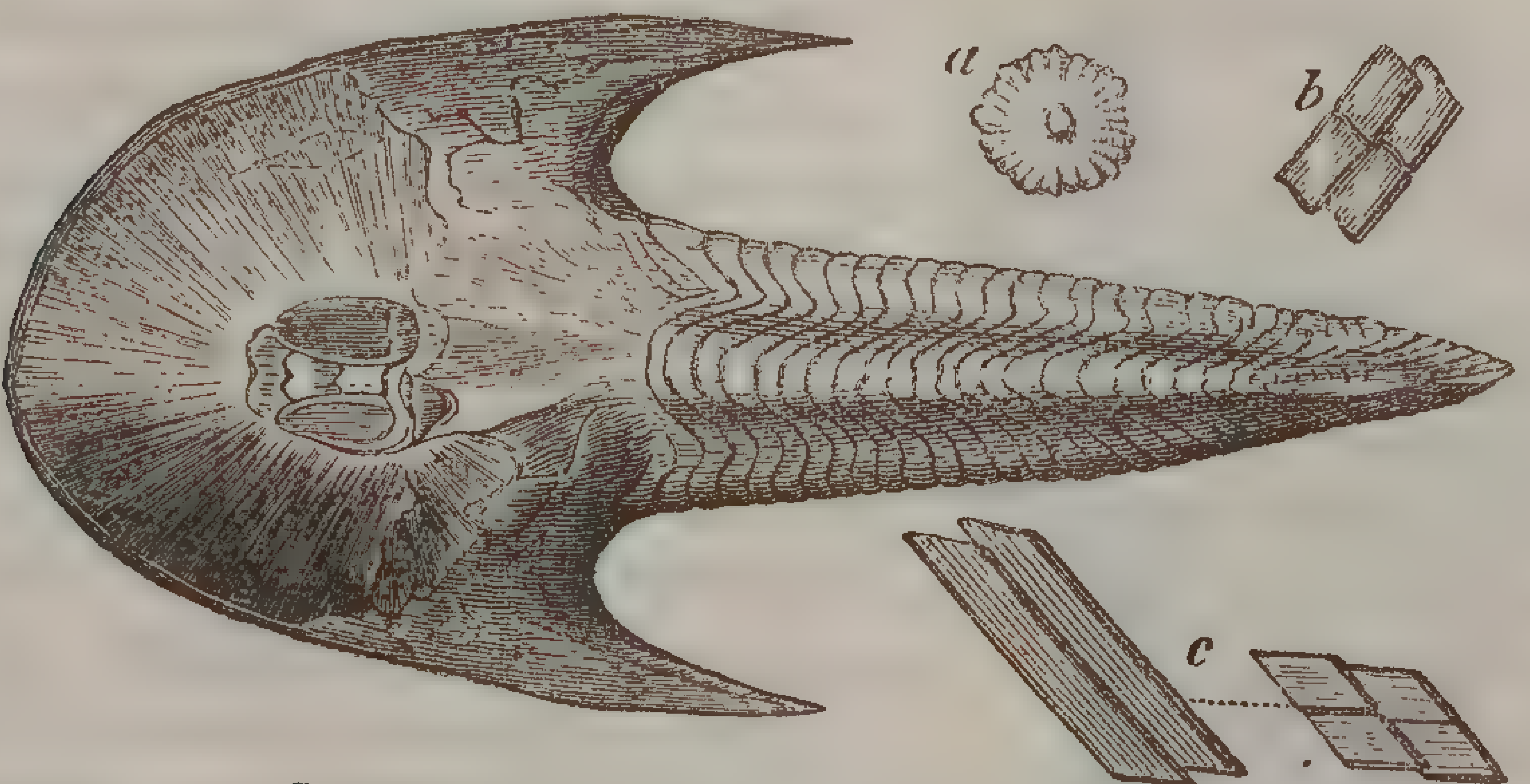
Fig. 540.



Scale of *Holoptychius nobilissimus*, Agas. Clashbinnie. Nat. size.

C. (*Table*, p. 416.)—The third or lowest division south of the Grampians consists of grey paving-stone and roofing-slate, with associated red and grey shales; these strata underlie a dense mass of conglomerate. In these grey beds several remarkable fish have been found of the genus named by Agassiz *Cephalaspis*, or "buckler-headed," from the extraordinary shield which covers the head (see fig. 541.), and which has often been mistaken for that of a trilobite, such as *Asaphus*.

Fig. 541.



Cephalaspis Lyellii, Agass. Length 6¾ inches.
From a specimen in my collection found at Glammiss, in Forfarshire; see other figures, Agassiz, vol. ii. tab. 1. *a*., and 1. *b*.

a. One of the peculiar scales with which the head is covered when perfect. These scales are generally removed, as in the specimen above figured.
b, *c*. Scales from different parts of the body and tail.

In the same rock at Carmylie, in Forfarshire, commonly known as the Arbroath paving-stone, fragments of a huge crustacean have been met with from time to time. They are called by the Scotch quarrymen the "Seraphim," from the wing-like form and feather-like ornament of the hinder part of the head, the part most usually met with. Agassiz, having previously referred some of these fragments to the class of fishes, was the first to recognize their true nature, and

Fig. 542.

Portions of the *Pterygotus anglicus*, Agassiz.

1. Middle portion of the "Seraphim" or back of the head, with the scale-like sculpturing.
2. Portion of the dilated base of one of the anterior feet, with its strong spines or teeth, used as masticating organs.
3. The proximal portion of one of the great anterior claws.
4. Termination of the same, with the serrated pincers. (See Agass. Poiss. Foss. du Vieux Grès Rouge, plate A.)

1. and 2. are of the natural size; 3. and 4. are reduced one half.

in the first plate of his "Poissons Fossiles du Vieux Grès Rouge," he figured the portions on which he founded his opinion.

The carapace of this huge crustacean, which must have rivalled, if not exceeded in size the largest crabs, is furnished at its hinder part with short prongs, and has two large eyes near the middle, much like those of the *Eurypterus* found in the coal formation of Glasgow. The body consists of ten or eleven moveable rings (the exact number is not ascertained), and was terminated by an oval-pointed tail. The whole surface is covered by the scale-like markings before mentioned as ornamenting the head. Prof. M'Coy, to whom I owe these notes on the general structure, has kindly furnished me with a restoration of the entire animal (fig. 543.), which he believes to be closely allied to the great *Eurypterus* before mentioned, if not of the very same genus, and, moreover, of the same family as the living King-crab or *Limulus*.

Fig. 543.

Pterygotus problematicus, Agassiz. Restoration by Professor M'Coy.

Sir R. Murchison has expressed some doubts * whether the grey beds of Forfarshire, containing the *Pterygotus*, may not be referable to the Upper Silurian or Upper Ludlow beds; but, as they are associated at Balrudderie with numerous specimens of *Cephalaspis*) the bony bucklers or head-pieces alone being preserved), apparently belonging to two species, I think it far more probable that they constitute a division of the "Old Red," and perhaps not so ancient a one as the bituminous schists (*b*, p. 422.) in the North of Scotland.

In the same grey paving-stones and coarse roofing slates in which the *Cephalaspis* and *Pterygotus* occur, in Forfarshire and Kincardineshire, the remains of grass-like plants abound in such numbers as to be useful to the geologist by enabling him to identify corresponding strata at distant points. Whether these be fucoids, as I formerly conjectured, or freshwater plants of the family *Fluviales*, as some botanists suggest, cannot yet be determined. They are often accompanied by fossils, called "berries" by the quarrymen, and which are not unlike the form which a compressed blackberry or raspberry might assume (see figs. 544. and 545.). Some of these were first observed in the year 1828, in grey sandstone of the same age as that of Forfarshire, at Parkhill near Newburgh, in the north of Fife, by Dr. Fleming. I afterwards found them on the north side of Strathmore, in the vertical shale beneath the conglomerate, and in the same beds in the Sidlaw Hills, at all the points where fig. 4. is introduced in the section, p. 48.

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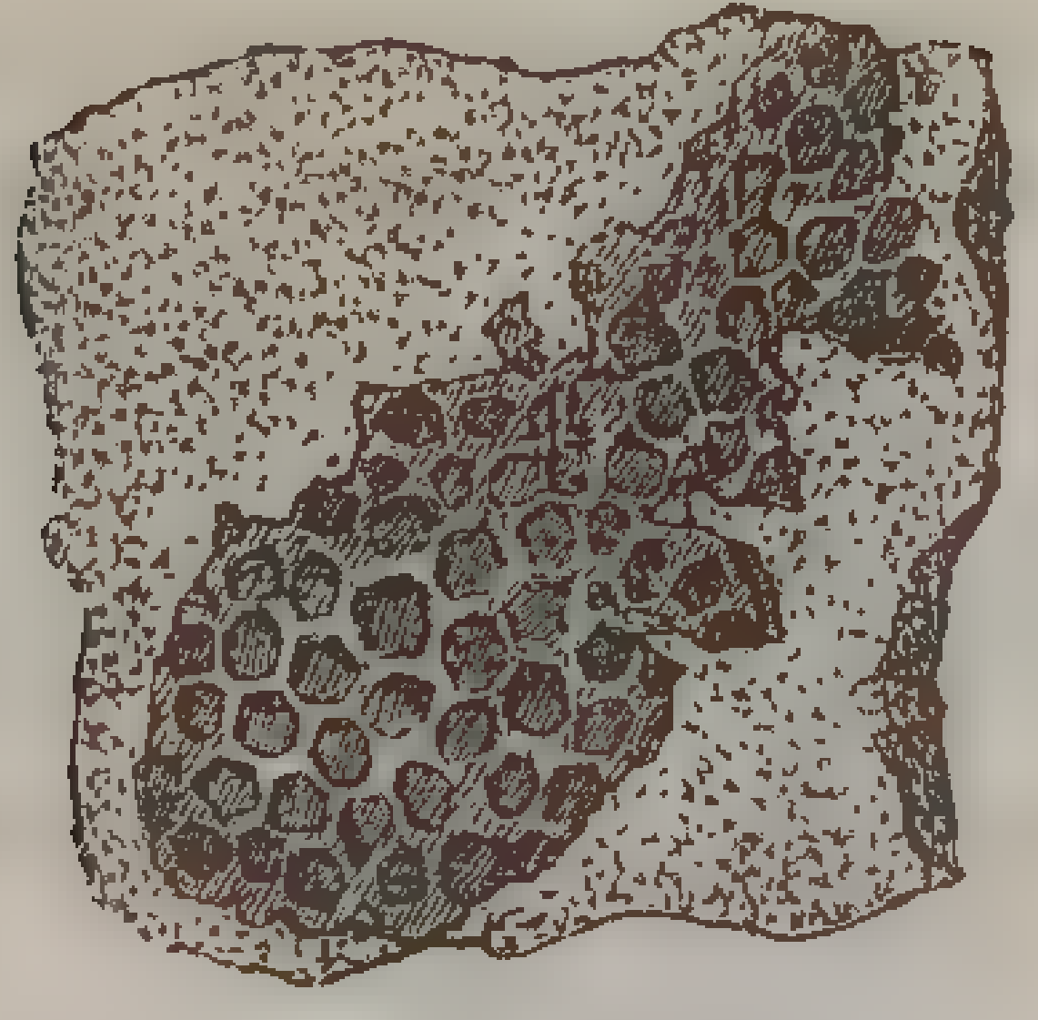
* Siluria, p. 247.

Fig. 544.



Parka decipiens, Fleming.
In sandstone of lower beds of Old Red, Ley's Mill, Forfarshire.

Fig. 545.

Parka decipiens, Fleming.
In shale of lower beds of Old Red, Fife.

Dr. Fleming has compared these fossils to the panicles of a *Juncus*, or the catkins of *Sparganium*, or some allied plant, and he was confirmed in this opinion by finding a specimen at Balrudderie, showing the under surface smoother than the upper, and displaying what may be the place of attachment of a stalk. I have met with some specimens in Forfarshire imbedded in sandstone, and not associated with the leaves of plants (see fig. 544.), which bore a considerable resemblance to the spawn of a recent *Natica* (fig. 546.), in which the eggs are arranged in a thin layer of sand, and seem to have acquired a polygonal form by pressing against each other; but, as no gasteropodous shells have been detected in the same formation, the *Parka* has probably no connection with this class of organisms.

Fig. 546.

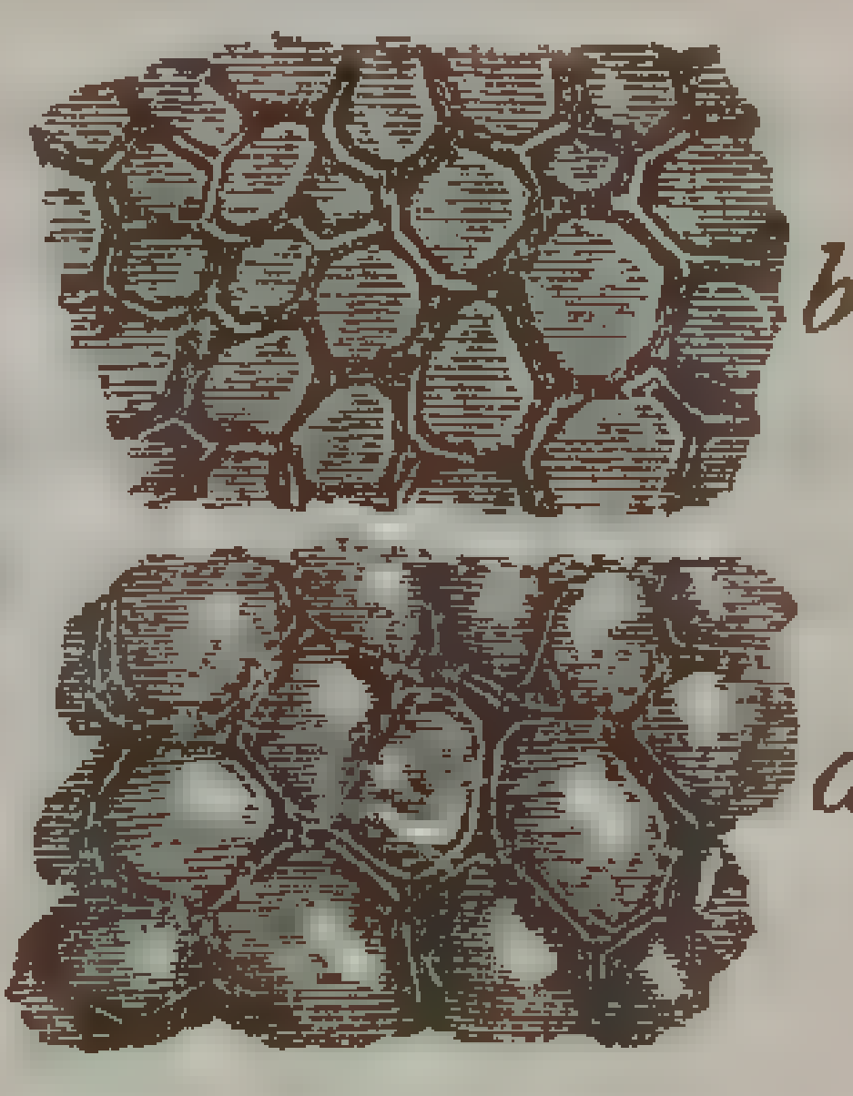
Fragment of spawn of British species of *Natica*.

The late Dr. Mantell was so much struck with the resemblance of one of my specimens (see fig. 547.) to a small bundle of the dried-up eggs of the common English frog, which he had obtained in a black and carbonaceous state (see fig. 548.) from the mud of a pond near London, that he suggested a

Fig. 547.

Fossil. — Old Red.

Fig. 548.



Recent.

Fig. 547. Slab of Old Red Sandstone, Forfarshire, with bodies like the ova of Batrachians. } Fossil.
- *a*. Ova? in a carbonized state.
- *b*. Egg cells?, the ova shed.

Fig. 548. Eggs of the common frog, *Rana temporaria*, in a carbonized state, from a dried-up pond in Clapham Common. } Recent.
- *a*. The ova.
- *b*. A transverse section of the mass exhibiting the form of the egg-cells.

Fig. 549.

Fig. 549. Shale of Old Red Sandstone, or Devonian, Forfarshire, with impression of plants and eggs of Batrachians?
- *a*. Two pair of ova? resembling those of large Salamanders or Tritons — on the same leaf.
- *b*, *b*. Detached ova?
- *c*. Egg-cells (?) of frogs or *Ranina*

batrachian origin for the fossil; and Mr. Newport concurred in the idea, adding that other larger and more circular fossils (fig. 549.), which I procured from shale in the same "Old Red," occurring singly or in pairs, and attached to the leaves of plants, might possibly be the ova of some gigantic triton or salamander.

The general absence of reptilian remains from strata of the Devonian period will weigh strongly with many geologists against such conjectures.

"Old Red" in the North of Scotland.—The whole of the northern part of Scotland, from Cape Wrath to the southern flank of the Grampians, has been well described by Mr. Hugh Miller as consisting of a nucleus of granite, gneiss, and other hypogene rocks, which seem as if set in a sandstone frame.* The beds of the Old Red Sandstone constituting this frame may once perhaps have extended continuously over the entire Grampians before the upheaval of that mountain range; for one band of the sandstone follows the course of the Moray Frith far into the interior of the great Caledonian valley, and detached hills and island-like patches occur in several parts of the interior, capping some of the higher summits in Sutherlandshire, and appearing in Morayshire like oases among the granite rocks of Strathspey. On the western coast of Ross-shire, the Old Red forms those three immense insulated hills before described (p. 67.), where beds of horizontal sandstone, 3000 feet high, rest unconformably on a base of gneiss, attesting the vast denudation which has taken place.

As the mineral character of the "Old Red" north of the Grampians differs considerably from that of the south, especially in the middle and lower divisions, I shall now allude to it separately. The upper portion, consisting of light-coloured sandstones, and containing the *Telerpeton* of Elgin, has been already classed, A., p. 416., as the equivalent of the yellow sandstone of Fife. That upper member passes downwards into red and variegated sandstone and conglomerate, which may correspond with the beds called B., in the same section at p. 416. To the above succeeds, in the descending order, "the middle formation" of Mr. Hugh Miller, composed of thin, fissile, grey sandstone, in which, in Morayshire, Dr. Malcolmson found a species of *Cephalaspis;* but whether these beds are of the age of the paving-stone of Arbroath (C., *Table*, p. 416.) is as yet uncertain.

Next below is the "inferior division" of Hugh Miller, comprising:—

a. *Red and variegated sandstones.*
b. *Bituminous schists.*
c. *Coarse sandstone.*
d. *Great conglomerate.*

In the schists *b*, a great variety of fish are met with in the counties of Banff, Nairn, Moray, Cromarty, and Caithness, and also in Orkney, belonging to the genera *Pterichthys* (fig. 550.), *Coccosteus, Diplopterus, Dipterus, Cheiracanthus, Asterolepis*, and others described by Agassiz.

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* "Old Red Sandstone," 1841.

Five species of *Pterichthys* have been found in this lowest division of the Old Red. The wing-like appendages, whence the genus is named, were first supposed by Mr. Miller to be paddles, like those of the turtle; but Agassiz regards them as weapons of defence, like the occipital spines of the River Bull-head (*Cottus gobio*, Linn.); and considers the tail to have been the only organ of motion. The genera *Dipterus* and *Diplopterus* are so named, because their two dorsal fins are so placed as to front the anal and ventral fins, so as to appear like two pair of wings. They have bony enamelled scales.

Fig. 550.

Pterichthys, Agassiz; upper side, showing mouth; as restored by H. Miller.*

The *Asterolepis* was a ganoid fish of gigantic dimensions. *A. Asmusii*, Eichwald, the species characteristic of the Old Red Sandstone of Russia, as well as that of Scotland, attained the length of between 20 and 30 feet. It was clothed with strong bony armour, embossed with star-like tubercles, but it had only a cartilaginous skeleton. The mouth was furnished with two rows of teeth, the outer ones small and fish-like, the inner larger and with a reptilian character.† The *Asterolepis* occurs also in the Devonian rocks of North America, in the lower division of the Old Red. Coniferous wood, with structure showing medullary rays, has likewise been detected in the lower division by Hugh Miller‡, who has pointedly dwelt on the importance of the fact, as the oldest example yet known of so highly organized a plant occurring in a rock of such antiquity.

South Devon and Cornwall.—Term Devonian.—A great step was made in the classification of the slaty and calciferous strata of South Devon and Cornwall in 1837, when a large portion of the beds, previously referred to the "transition" or Silurian series, were found to belong in reality to the period of the Old Red Sandstone. For this reform we are indebted to the labours of Professor Sedgwick and Sir R. Murchison, assisted by a suggestion of Mr. Lonsdale, who, in 1837, after examining the South Devonshire fossils, perceived that some of them agreed with those of the Carboniferous group, others with those of the Silurian, while many could not be assigned to either system, the whole taken together exhibiting a peculiar and intermediate character. But these paleontological observations alone would not have enabled us to assign, with accu-

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* Old Red Sandstone. Plate 1. fig. 1. Mr. Miller's description of the fish is most graphic and correct.

† Footprints of the Creator, by Hugh Miller.

‡ Footprints, p. 199.

racy, the true place in the geological series of these slate-rocks and limestones of South Devon, had not Messrs. Sedgwick and Murchison, in 1836 and 1837, discovered that the culmiferous or anthracitic shales of North Devon belonged to the Coal, and not, as preceding observers had imagined, to the "transition" period.

As the strata of South Devon here alluded to are far richer in organic remains than the red sandstones of contemporaneous date in Herefordshire and Scotland, the new name of the "Devonian system" was proposed as a substitute for that of Old Red Sandstone.

The link supplied by the whole assemblage of imbedded fossils, connecting as it does the paleontology of the Silurian and Carboniferous groups, is one of the highest interest, and equally striking whether we regard the *genera* of the corals or of the shells. The *species* are mostly distinct except in the upper group.

The rocks of this group in South Devon consist, in great part, of green chloritic slates, alternating with hard quartzose slates and sandstones. Here and there calcareous slates are interstratified with blue crystalline limestone, and in some divisions conglomerates, passing into red sandstone. But the whole series is much altered and disturbed by the intrusion of the granite of Dartmoor and other igneous rocks.

In North Devon, on the contrary, the Devonian group has been less changed, and its relations to the overlying carboniferous rocks or "Culm Measures" are clearly seen. The following sequence is exhibited in the coast section on the Bristol Channel between Barnstaple and the North Foreland.*

Devonian Series in North Devon.

Upper	1.	*a.* Calcareous brown slates; with fossils, many of them common to the Carboniferous group. (Barnstaple, Pilton, &c.) *b.* Brown and yellow sandstone, with shells and land-plants—*Stigmaria, Knorria,* and others. (Baggy Point, Marwood, &c.)
Middle	2.	Hard grey and reddish sandstones and micaceous flags, without fossils, resting on soft greenish schists of considerable thickness. (Morte Bay, Bull Point, &c.)
	3.	Calcareous slates, with eight or nine courses of limestone, full of corals and shells like those of the Plymouth limestone. (Combe Martin, Ilfracombe Harbour, &c.)
Lower	4.	Hard, greenish, red, and purple sandstones: with occasional fossils, *Spirifers,* &c. (Linton, North Foreland, &c.)
	5.	Soft chloritous slates, with some sandstones; *Orthis, Spirifer,* and some Corals. (Valley of Rocks, Lynmouth, &c.)

The successive beds of this section have been compared with those of South Devon and Cornwall both by the authors of the "Devonian" system and by other observers. And Prof. Sedgwick has again lately brought them into closer comparison.† Other geologists at home and abroad have successively identified them with the Devonian series in France, Belgium, the Rhenish Provinces,

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* Sedgwick and Murchison, Trans. Geol. Soc., New Series, vol. v. p. 644. De la Beche, Geol. Report, Devon and Cornwall, pl. 3. Murchison's Siluria, p. 256.

† Quart. Journ. Geol. Soc., vol. viii. p. 1., *et seq.*

Central Germany, and America.* I shall proceed first to treat of the main divisions which have been established in Europe.

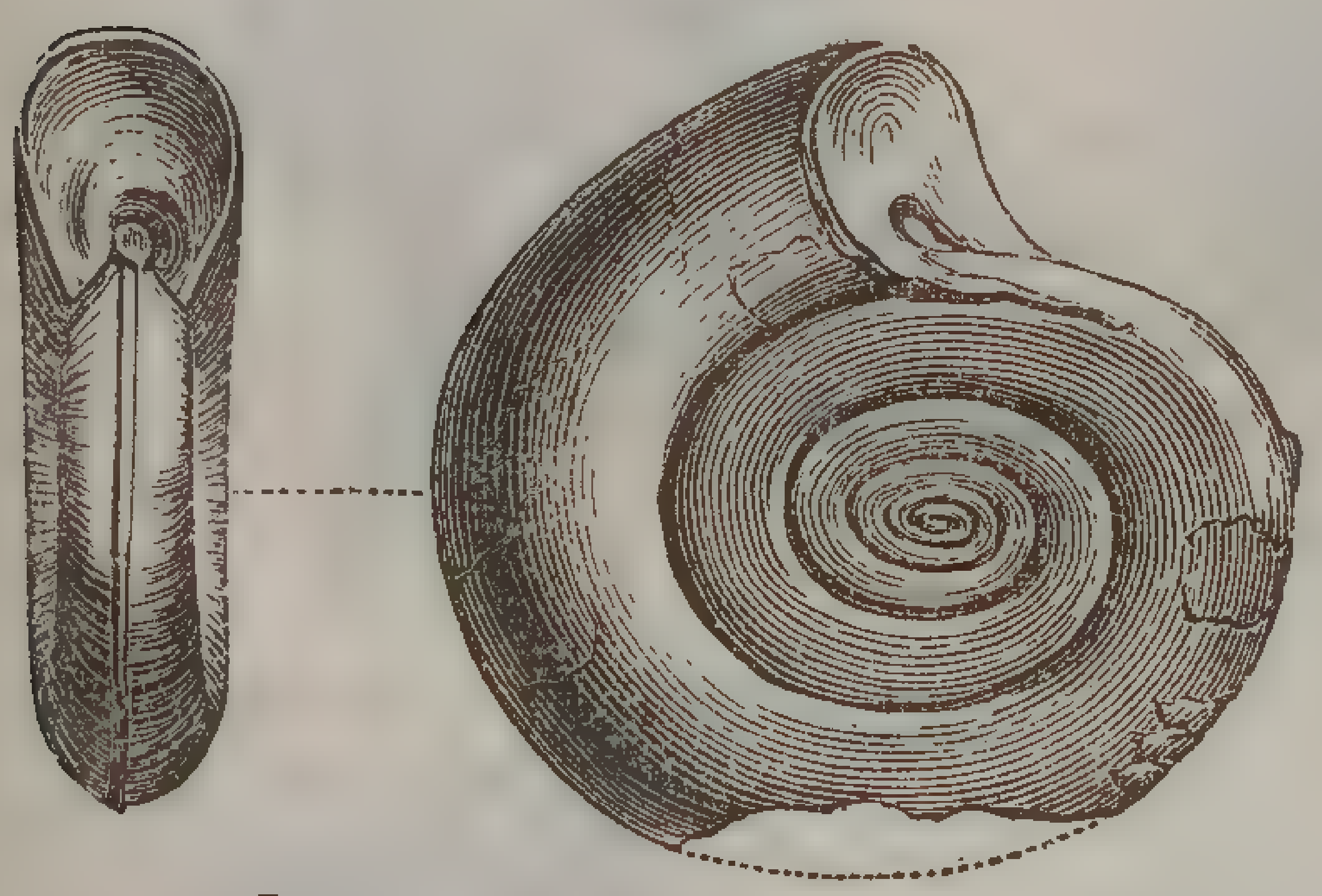
Upper Devonian Rocks.

The slates and sandstones of Barnstaple (No. 1. *a, b.* of the preceding section) are represented in Cornwall by the limestones and slates of Petherwyn, which rise in like manner from under the Culm Measures, constituting the Petherwyn group of Prof. Sedgwick. These beds contain the very common *Spirifer disjunctus*, Sow. (*S. Verneuilii*, Murch.), (see fig. 551.), a species distributed over the whole of Europe, and found even in Asia Minor and China. Among many other fossils the *Clymenia linearis* (fig. 552.) and the minute crustacean *Cypridina serrato-striata* (fig. 553.) are so characteristic of these upper beds in Belgium, the Rhenish Provinces, the Hartz, Saxony, and Silesia, that strata of this division in Germany are distinguished by the names of "Clymenien-Kalk," and "Cypridinen-schiefer."†

Fig. 551.

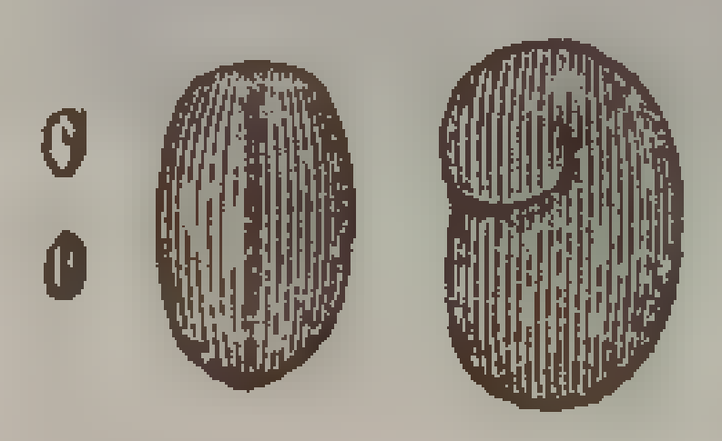
Spirifer disjunctus, Sow. Syn. *Sp. Verneuilii*, Murch.
Upper Devonian, Boulogne.

Fig. 552.



Clymenia linearis, Munster.
Petherwyn, Cornwall; Elbersreuth, Bavaria.

Fig. 553.



Cypridina serrato-striata, Sandberger.
Weilburg, &c.; Nassau; Saxony; Belgium.

With these are many *Goniatites* (*G. subsulcatus*, Münster, and other species) both in England and on the continent. In Germany they are usually confined to distinct beds, as at Oberscheld, also at Couvin in Belgium, &c. Trilobites are not unfrequent in Cornwall and North Devon; they are chiefly restricted to species of *Phacops* (for genus, see fig. 585.); but in the upper Devonian limestones of the Fichtelgebirge, as at Elbersreuth in Bavaria, there are numerous genera and species which never rise higher in the series or appear in any portion of the carboniferous limestone.

Middle Devonian.

The unfossiliferous series (No. 2., p. 424.) of North Devon, and the calcareous beds of Ilfracombe (3.), correspond to the Dartmouth and

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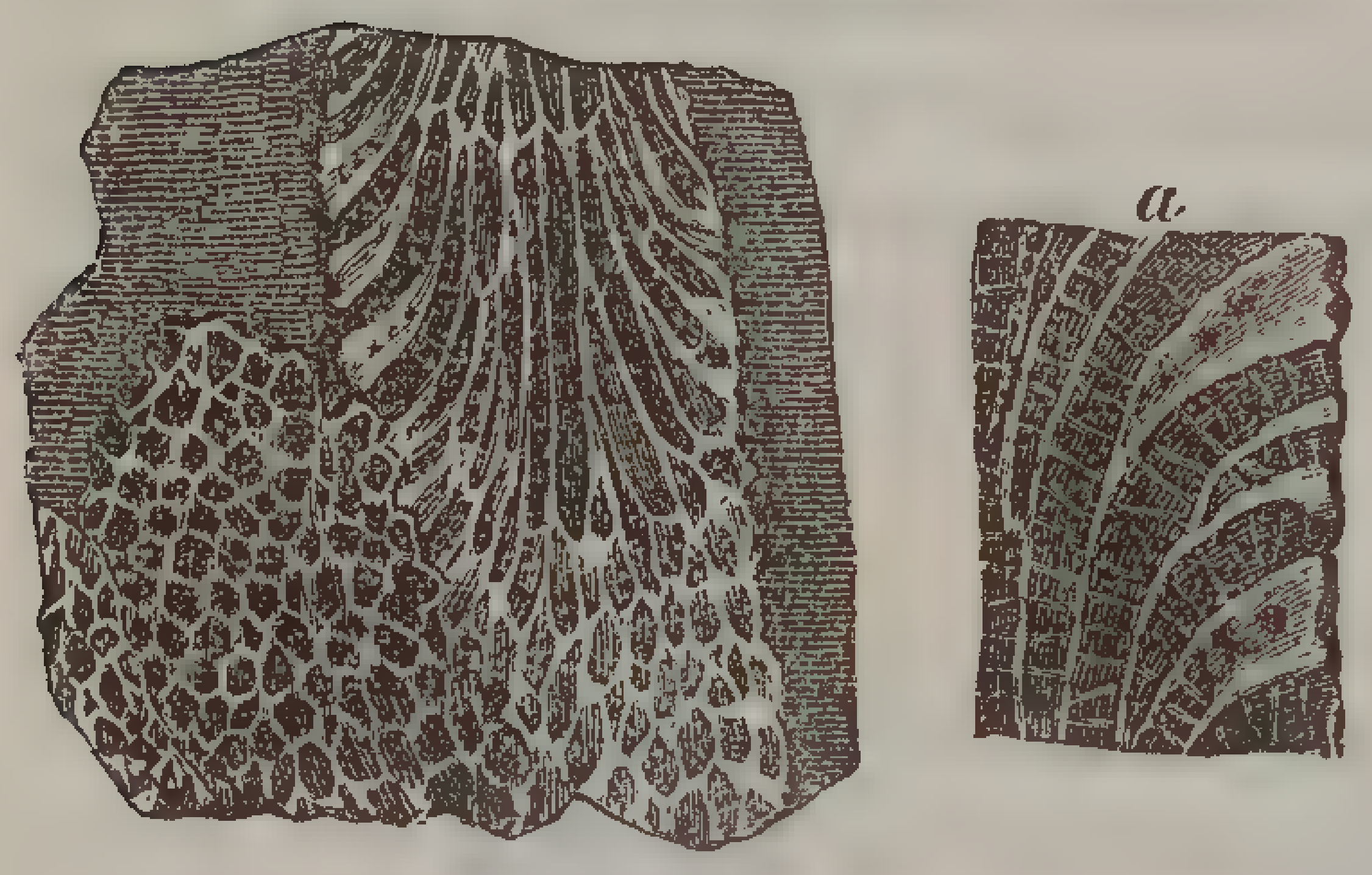
* See Dr. Fred. Sandberger on the Devonian rocks of Nassau (Geol. Verhalt. Nassau); Fred. Roemer, on the Hartz Devonian Rocks, in Dunker and Von Meyer's Palæontographica, 3rd vol. pt. 1.

† See Murchison's Siluria, chaps. x., xiv., and xv.

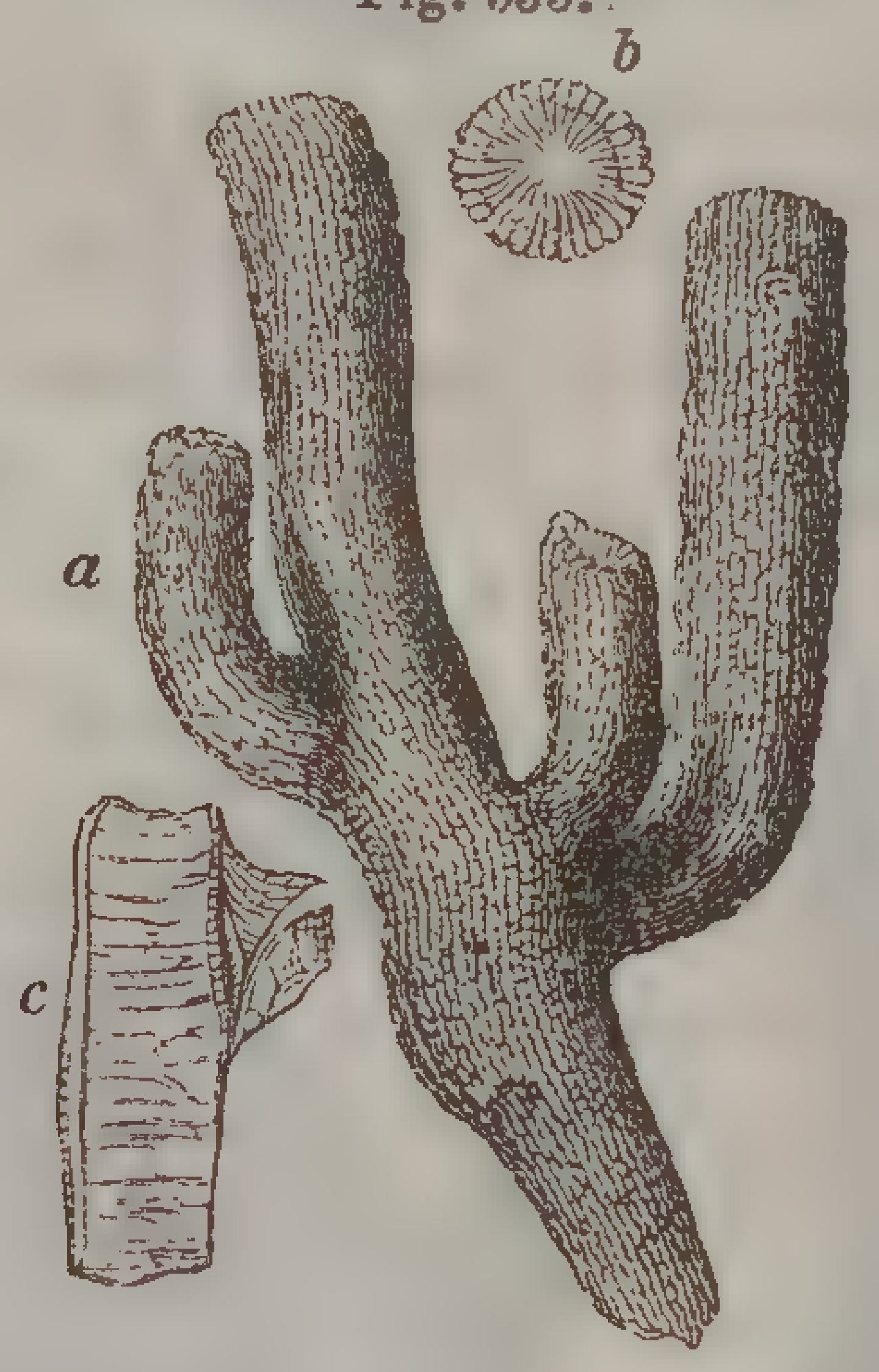
Plymouth groups of Prof. Sedgwick's South Devon series, and are the most typical portion of the Devonian system. They include the great limestones of Plymouth and Torbay, replete with shells, trilobites, and corals. A thick accumulation of slate and schist, full of the same fossils, occupies nearly all the southern portion of Devonshire and a large part of Cornwall. Among the corals we find the genera *Favosites*, *Heliolites*, and *Cyathophyllum*, the last genus equally abundant in the Silurian and Carboniferous systems, the two former so frequent in Silurian rocks. Some few even of the species are common to the Devonian and Silurian groups, as, for example, *Favosites polymorpha* (fig. 554.), one of the commonest of all the Devonshire fossils. The *Cyathophyllum cæspitosum* (fig. 555.) and *Heliolites pyriformis* (fig. 556.) are peculiarly characteristic; as is another very common species, the *Aulopora serpens* (fig. 557.), which creeps over corals and shells in its young state, as here figured, but afterwards grows upwards and becomes a cluster of tubes connected by minute processes. In this state it has been supposed to be a distinct coral, and has been called *Syringopora*.

Fig. 554.



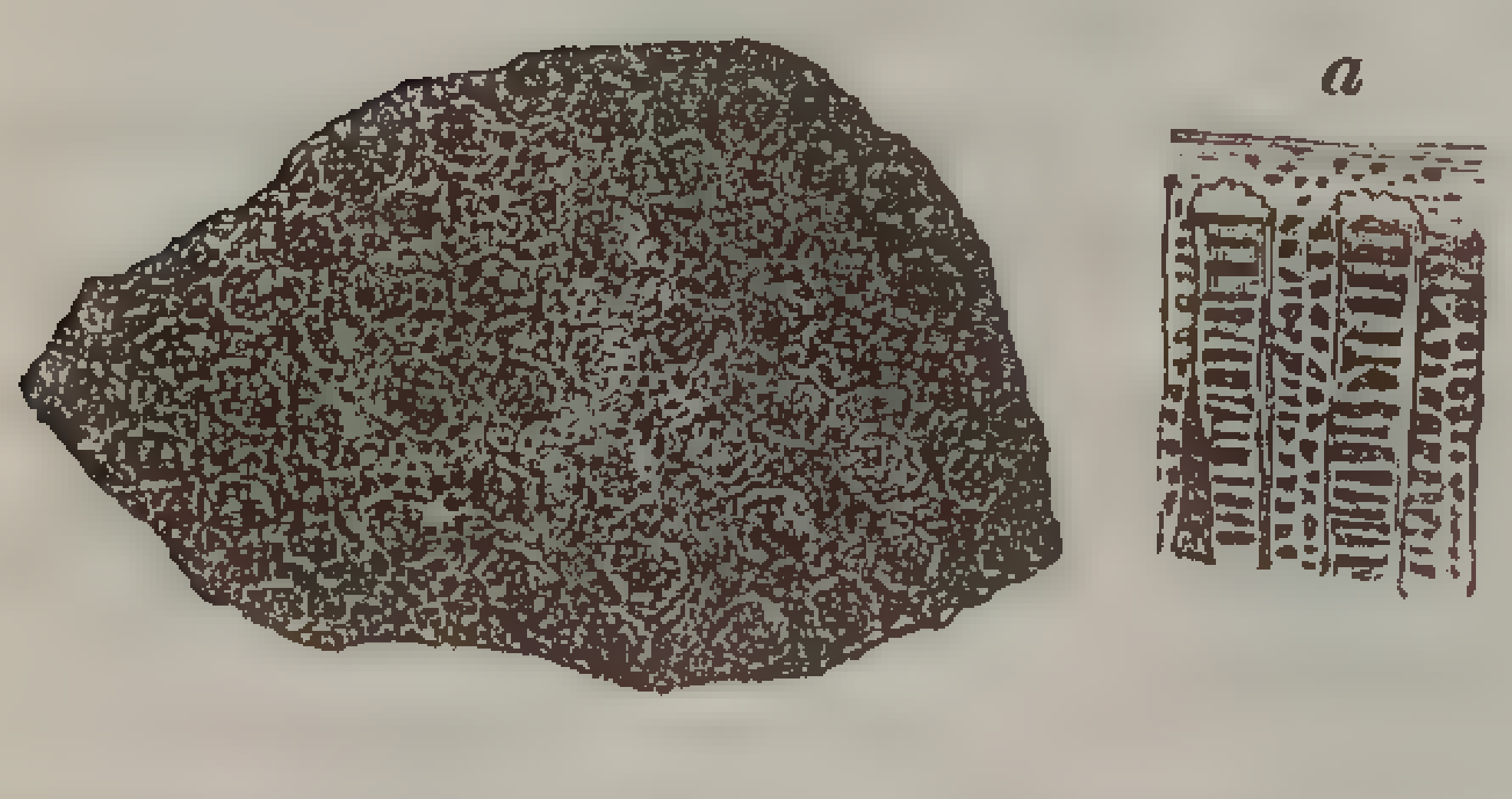
Favosites polymorpha, Goldf. S. Devon, from a polished specimen.
a. Portion of the same magnified, to show the pores.

Fig. 555.



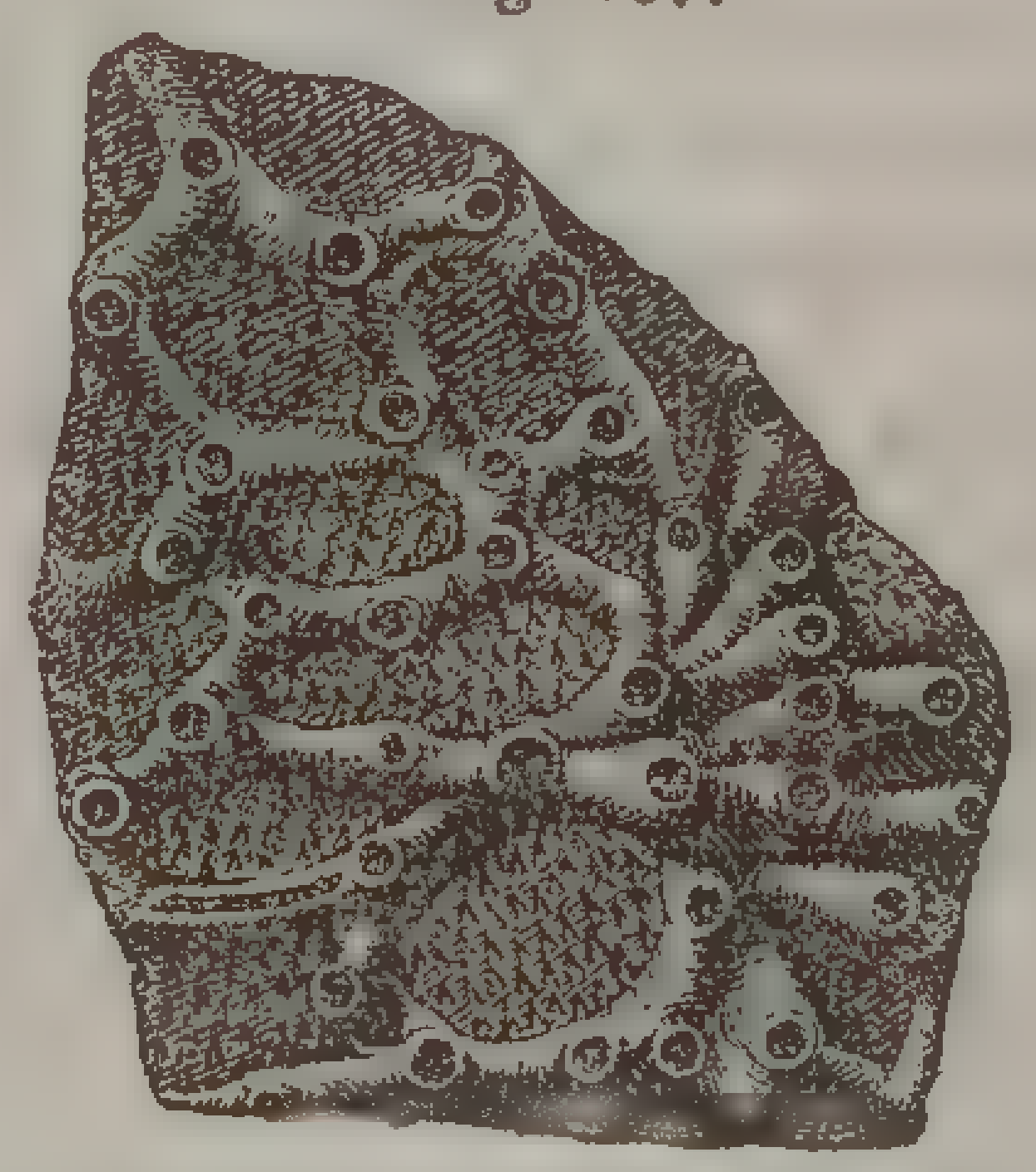
a. *Cyathophyllum cæspitosum*, Goldf. Plymouth.
b. a terminal star.
c. vertical section, exhibiting transverse plates, and part of another branch.

Fig. 556.



Heliolites porosa, Goldf., sp. *Porites pyriformis*, Lonsd.
a. portion of the same magnified. Middle Devonian, Torquay; Plymouth; Eifel.

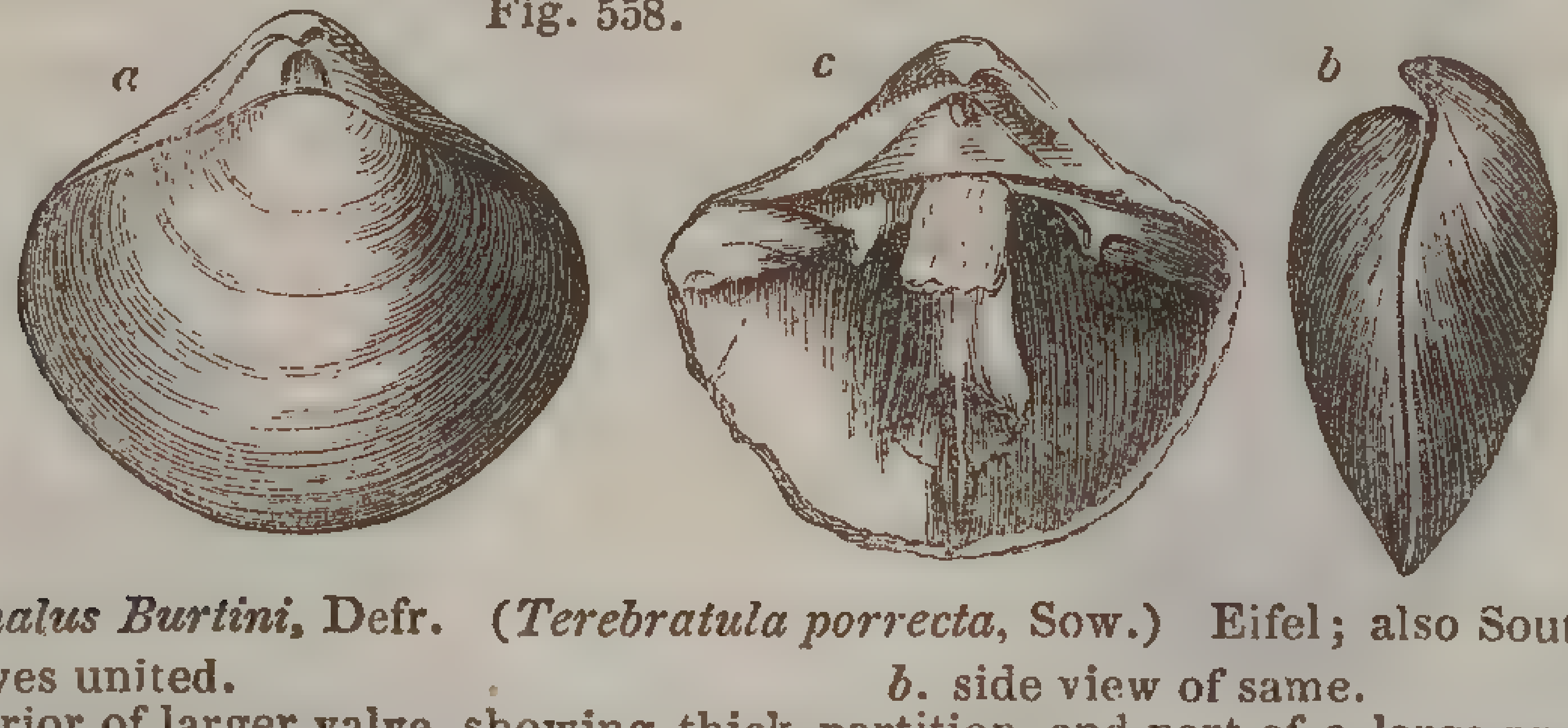
Fig. 557.



Aulopora serpens, Goldf.
(The young basal portion of a *Syringopora*, Milne Edw. and Haime.)

With the above are found many stone-lilies or crinoids, some of them, such as *Cupressocrinites*, of forms generically distinct from those of the Carboniferous Limestone. The mollusks also are no less characteristic, among which the genus *Stringocephalus* (fig. 558.)

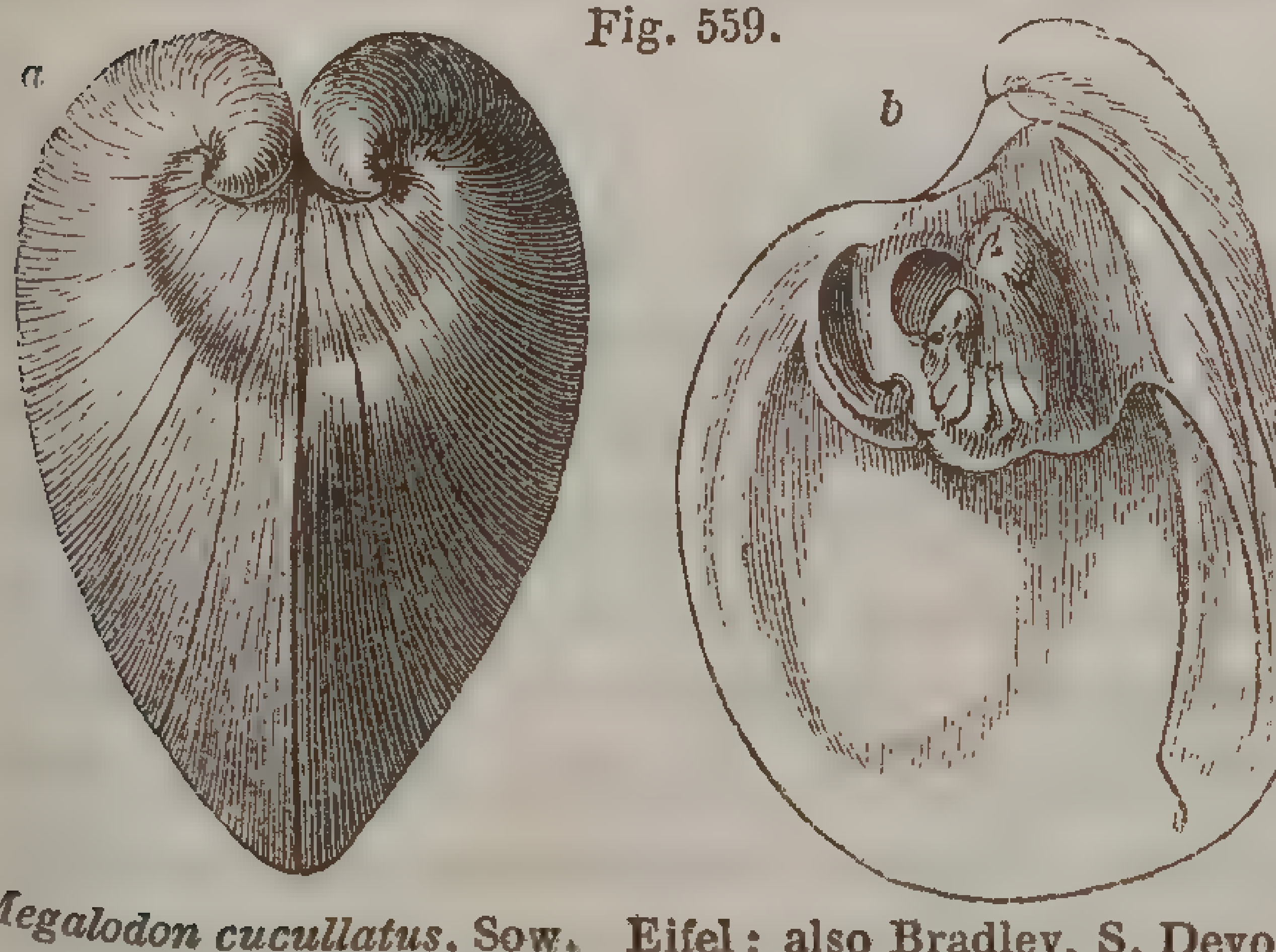
Fig. 558.



Stringocephalus Burtini, Defr. (*Terebratula porrecta*, Sow.) Eifel; also South Devon.
a. valves united. b. side view of same.
c. interior of larger valve, showing thick partition, and part of a large process which projects from its upper end quite across the shell.

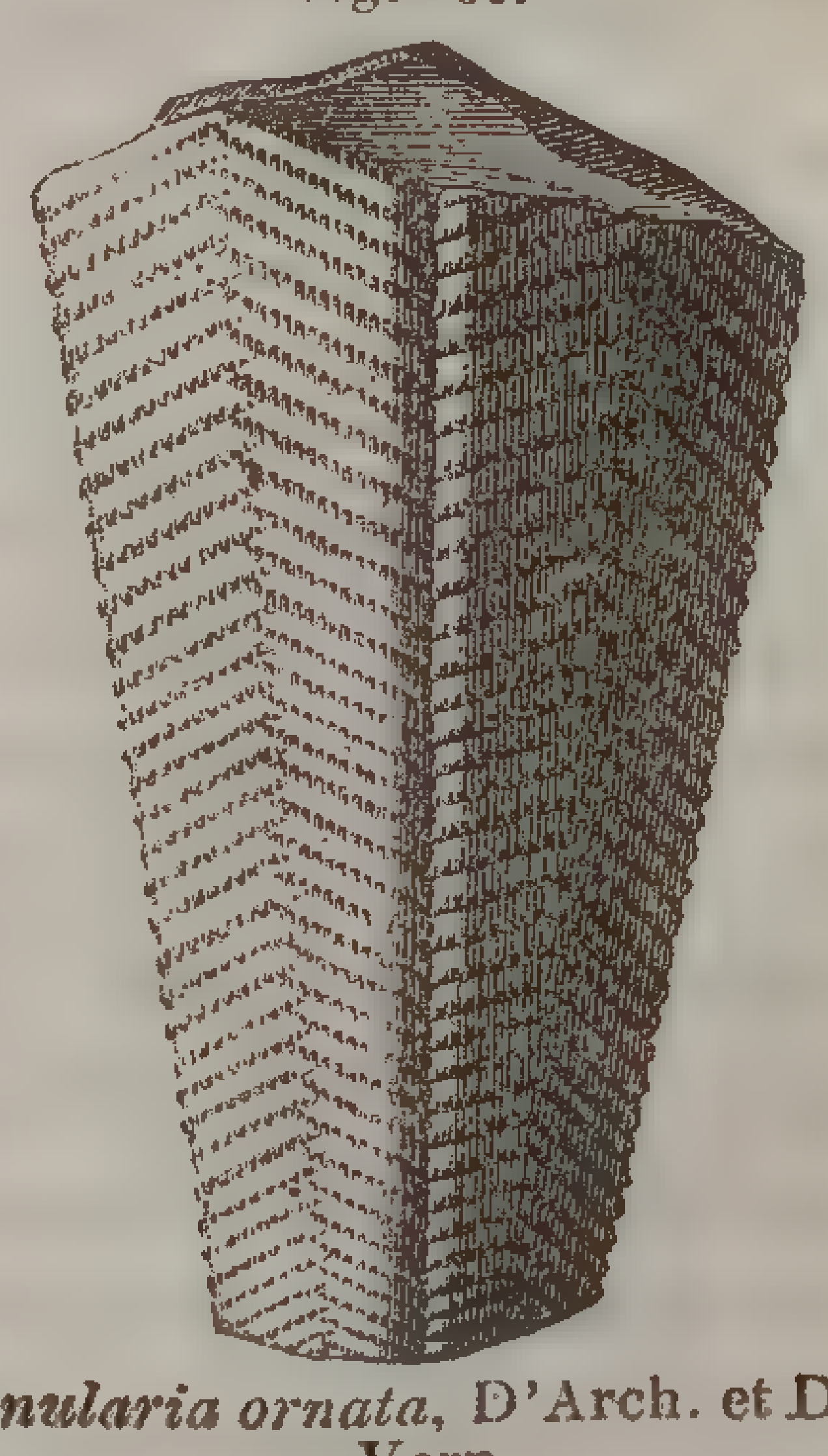
may be mentioned as exclusively Devonian. Many other Brachiopod shells, of the genus *Spirifer*, &c., abounded, and among them the *Atrypa reticularis*, Linn. sp. (fig. 575. p. 438.), which seems to have been a cosmopolite species occurring in Devonian strata from America to Asia Minor, and which, as we shall hereafter see (p. 437.), lived also in the Silurian seas. Among the peculiar lamellibranchiate bivalves common to the Plymouth limestone of Devonshire and the Continent, we find the *Megalodon* (fig. 559.), together with many spiral univalves, such as *Murchisonia*, *Euomphalus*, and *Macrocheilus*; and Pteropods such as *Conularia* (fig. 560.).

Fig. 559.



Megalodon cucullatus, Sow. Eifel; also Bradley, S. Devon.
a. the valves united.
b. interior of valve, showing the large cardinal tooth.

Fig. 560.



Conularia ornata, D'Arch. et De Vern.
(Geol. Trans. 2d s. vol. vi. pl. 29.)
Refrath, near Cologne.

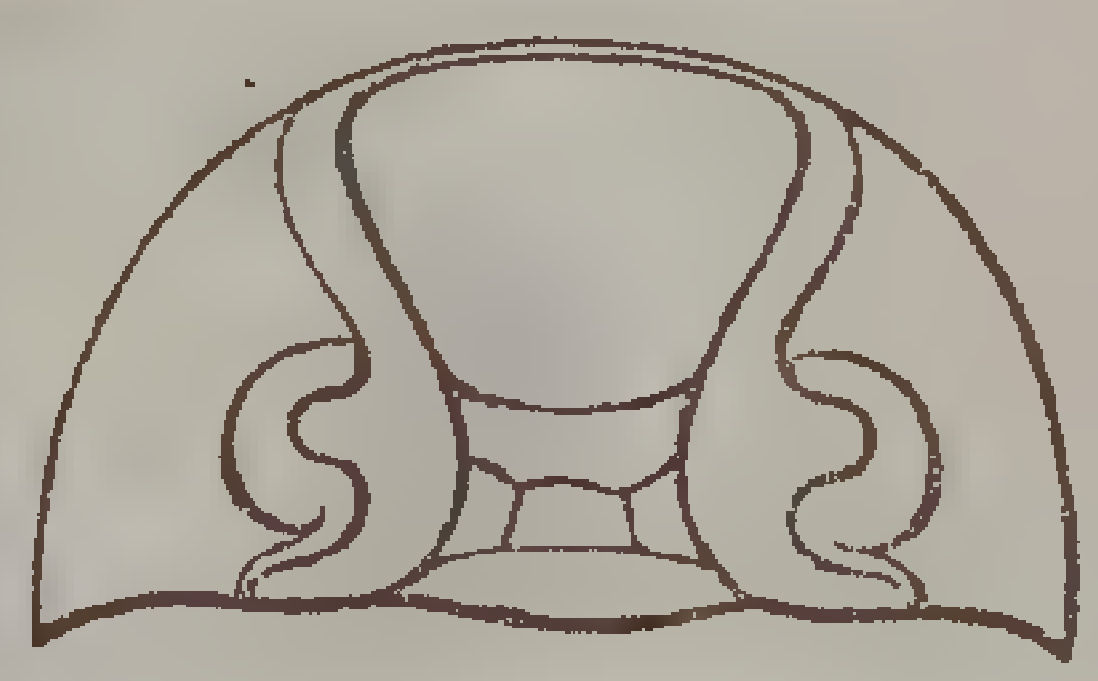
The cephalopoda, such as *Cyrtoceras*, *Gyroceras*, and others, are nearly all of genera distinct from those prevailing in the Upper Devonian Limestone, or Clymenien-kalk of the Germans already mentioned (p. 425.). Although but few species of Trilobites occur, the characteristic *Brontes flabellifer* (fig. 561. p. 428.) is far from rare, and all collectors are familiar with its fan-like tail. The head is seldom found perfect; a restoration of it has been attempted by Mr. Salter (fig. 562.)

In this same formation, comprising in it the "Stringocephalus

Fig. 561.

Brontes flabellifer, Goldf. Eifel; also S. Devon.

Fig. 562.

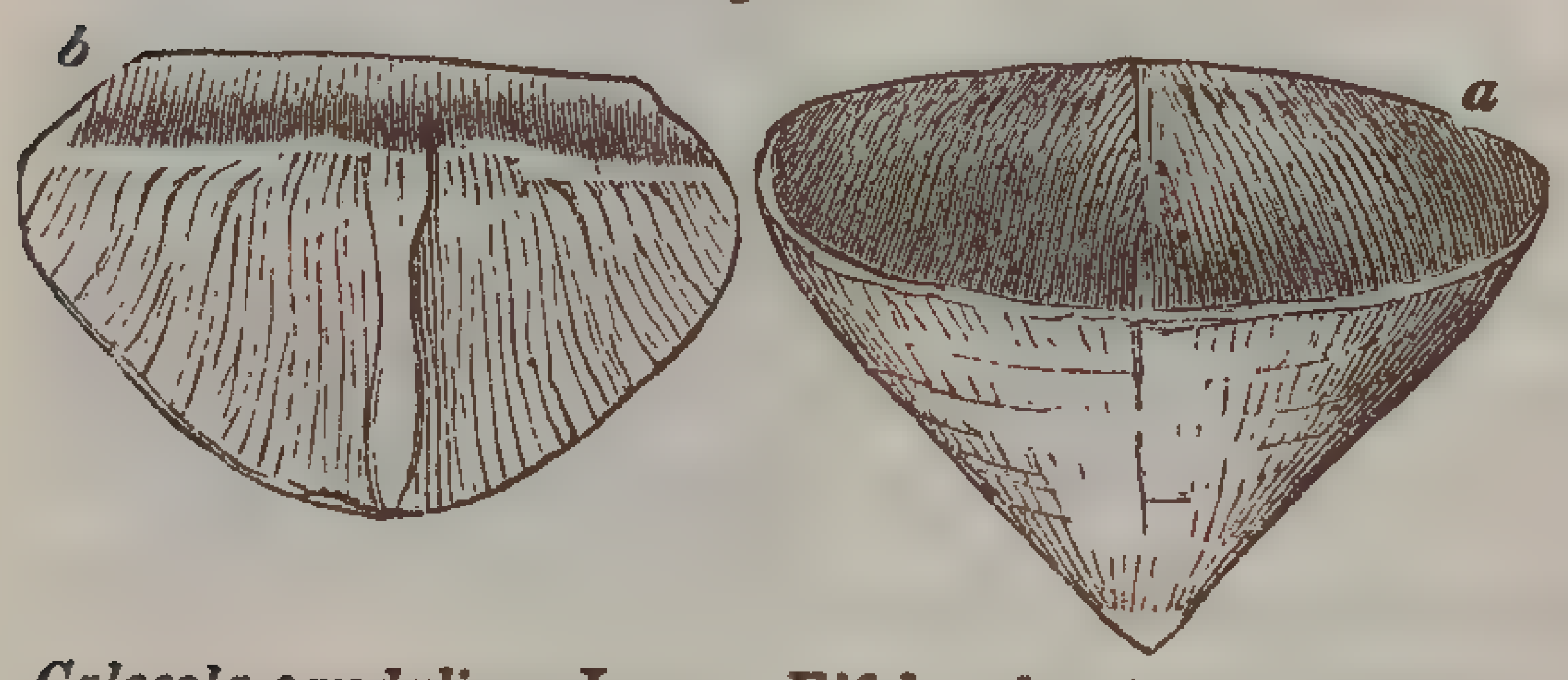


Restored outline of head of *Brontes flabellifer*.

limestone," or "Eifel Limestone" of Germany, several remains of *Coccosteus* and other ichthyolites have been detected, and they serve, as Sir R. Murchison observes (Siluria, p. 371.), to identify the rock with the Old Red Sandstone of Britain and Russia.

Beneath the great Eifel Limestone (the principal type of "the Devonian" on the Continent), lie certain schists called by German writers "Calceola-schiefer" because they contain in abundance a fossil brachiopod of very curious structure, *Calceola sandalina* (fig. 563.).

Fig. 563.

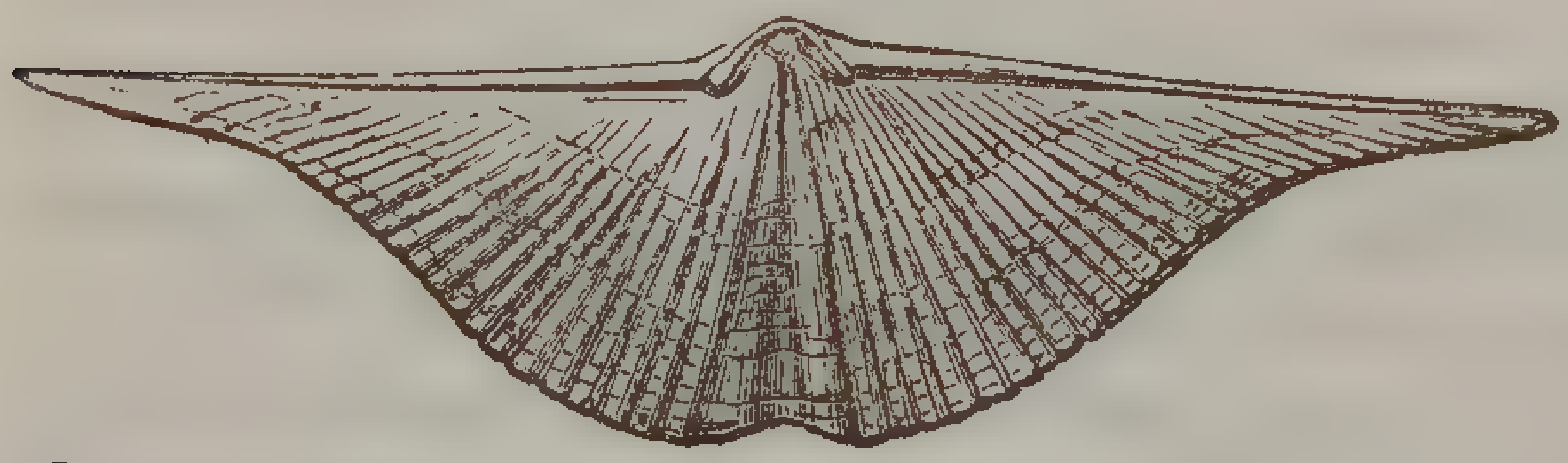


Calceola sandalina, Lam. Eifel; also South Devon. *a*, ventral valve. *b*. inner side of dorsal valve.

Lower Devonian.

Beneath the Middle Devonian limestones and schists already enumerated, a series of slaty beds and quartzose sandstones, the latter constituting the "Older Rhenish Greywacke" of Roemer, and the "Spirifer sandstone" of Sandberger, are exhibited between Coblentz and Caub.* A portion of these rocks on the Rhine and in some of the adjacent countries were regarded as "Upper Silurian" by Prof. Sedgwick and Sir R. Murchison in 1839, but their true age has since been determined. Their equivalents are found in England in the sandstones and slates of the North Foreland and Linton in Devon (Nos. 4. and 5. of the section, p. 424.), and, according to Mr. Salter, in the sandstone of Torbay in South Devon, where many of the characteristic Rhenish fossils are met with. The broad-winged Spirifers which distinguish the "Spirifer-sandstein" of Germany have their representatives in the Devonian strata of N. America (see fig. 564.).

Fig. 564.



Spirifer mucronatus, Hall. Devonian of Pennsylvania.

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* Murchison's Siluria, p. 368.

Among the Trilobites of this era a large species of *Homalonotus* (fig. 565.) is conspicuous. The genus is still better known as a Silurian form, but the spinose species appear to belong exclusively to the "Lower Devonian."

With the above are associated many species of Brachiopods, such as *Orthis*, *Leptæna*, and *Chonetes*, and some Lamellibranchiata, such as *Pterinea;* also the very remarkable fossil coral, called *Pleurodictyum problematicum* (fig. 566.)

Fig. 565.

Homalonotus armatus, Burmeister. Lower Devonian; Daun, in the Eifel.

Obs. The two rows of spines down the body give an appearance of more distinct trilobation than really occurs in this or most other species of the genus.

Fig. 566.

Pleurodictyum problematicum, Goldfuss. Lower Devonian; Dietz, Nassau, &c.

Obs. Attached to a worm-like body (*Serpula*). The specimen is a cast in sandstone, the thin expanded base of the coral being removed. and exposing the large polygonal cells; the walls of these cells are perforated, and the casts of these perforations produce the chain-like rows of dots between the cells.

Devonian of Russia.—The Devonian strata of Russia extend, according to Sir R. Murchison, over a region more spacious than the British Isles; and it is remarkable that, where they consist of sandstone like the "Old Red" of Scotland and Central England, they are tenanted by fossil fishes often of the same species and still oftener of the same genera as the British, whereas when they consist of limestone they contain shells similar to those of Devonshire, thus confirming, as Sir Roderick observes, the contemporaneous origin previously assigned to formations exhibiting two very distinct mineral types in different parts of Britain.* The calcareous and the arenaceous rocks of Russia above alluded to alternate in such a manner as to leave no doubt of their having been deposited at the same period. Among the fish common to the Russian and the British strata are *Asterolepis Asmusii* before mentioned; a smaller species, *A. minor*, Ag.; *Holoptychius nobilissimus* (p. 418.); *Dendrodus strigatus*, Owen; *Pterichthys major*, Ag.; and many others. But some of the most marked of the Scottish genera, such as *Cephalaspis*, *Coccosteus*, *Diplacanthus*, *Cheiracanthus*, &c., have not yet been found in Russia, owing perhaps to the present imperfect state of our researches, or possibly to geographical causes limiting the range of

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* Siluria, p. 329.

the extinct species. On the whole, no less than forty species of placoid and ganoid fish have been already collected in Russia, some of the placoids being of enomous size, as before stated, p. 423.

Devonian Strata in the United States.

In no country hitherto explored is there so complete a series of strata intervening between the Carboniferous and Silurian as in the United States. This intermediate or Devonian group was first studied in all its details, and with due attention to its fossil remains, by the Government Surveyors of New York. In its geographical extent, that State, taken singly, is about equal in size to Great Britain; and the geologist has the advantage of finding the Devonian rocks there in a nearly horizontal and undisturbed condition, so that the relative position of each formation can be ascertained with certainty.

Subdivisions of the New York Devonian Strata, in the Reports of the Government Surveyors.

Names of Groups.	Thickness in Feet.
1. Catskill group or Old Red Sandstone	2000
2. Chemung group	1500
3. Portage	1000
4. Genessee	
5. Tully	15
6. Hamilton	1000
7. Marcellus	50
8. Corniferous	50
9. Onondaga	
10. Schoharie	10
11. Cauda-Galli grit	
12. Oriskany sandstone	5 to 30

These subdivisions are of very unequal value, whether we regard the thickness of the beds or the distinctness of their fossils; but they have each some mineral or organic character to distinguish them from the rest. Moreover, it has been found, on comparing the geology of other North American States with the New York standard, that some of the above-mentioned groups, such as Nos. 2. and 3., which are respectively 1500 and 1000 ft. thick in New York, are very local and thin out when followed into adjoining States; whereas others, such as Nos. 8. and 9., the total thickness of which is scarcely 50 feet in New York, can be traced over an area nearly as large as Europe.

Respecting the upper limit of the above system, there has been very little difference of opinion, since the Red Sandstone No. 1. contains *Holoptychius nobilissimus* and other fish characteristic generically or specifically of the European Old Red. More doubt has been entertained in regard to the classification of Nos. 10, 11, and 12. M. de Verneuil proposed in 1847, after visiting the United States, to include the Oriskany sandstone in the Devonian; and Mr. D. Sharpe, after examining the fossils which I had collected in

America in 1842, arrived independently at the same conclusion.* The resemblance of the Spirifers of this Oriskany sandstone to those of the Lower Devonian of the Eifel was the chief motive assigned by M. de Verneuil for his view; and the overlying Schoharie grit, No. 10., was classed as Devonian because it contained a species of *Asterolepis*. On the other hand, Prof. Hall adduces many fossils from Nos. 10. and 12. which resemble more nearly the Ludlow group of Murchison than any other European type; and he thinks, therefore, that those groups may be "Upper Silurian." Although the Oriskany sandstone is no more than 30 feet thick in New York, it is sometimes 300 feet thick in Pennsylvania and Virginia, where, together with other primary or paleozoic strata, it has been well studied by Professors W. B. and H. D. Rogers.

The upper divisions (from the Catskill to the Genessee groups, inclusive, Nos. 1. to 4.) consist of arenaceous and shaly beds, and may have been of littoral origin. They vary greatly in thickness, and few of them can be traced into the "far west;" whereas the calcareous groups, Nos. 8. and 9., although in New York they have seldom a united thickness of more than 50 feet, are observed to constitute an almost continuous coral-reef over an area of not less than 500,000 square miles, from the State of New York to the Mississippi, and between Lakes Huron and Michigan, in the north, and the Ohio River and Tenessee in the south. In the Western States they are represented by the upper part of what is termed "the Cliff Limestone." There is a grand display of this calcareous formation at the falls or rapids of the Ohio River at Louisville in Kentucky, where it much resembles a modern coral-reef. A wide extent of surface is exposed in a series of horizontal ledges, at all seasons when the water is not high; and, the softer parts of the stone having decomposed and wasted away, the harder calcareous corals stand out in relief, their erect stems sending out branches precisely as when they were living. Among other species I observed large masses, not less than 5 feet in diameter, of *Favosites gothlandica*, with its beautiful honeycomb structure well displayed, and, by the side of it, the *Favistella*, combining a similar honeycombed form with the star of the *Astræa*. There was also the cup-shaped *Cyathophyllum*, and the delicate network of the *Fenestella*, and that elegant and well-known European species of fossil, called "the chain coral," *Catenipora escharoides* (see fig. 579. p. 439.), with a profusion of others. These coralline forms were mingled with the joints, stems, and occasionally the heads of lily encrinites. Although hundreds of fine specimens have been detached from these rocks to enrich the museums of Europe and America, another crop is constantly working its way out, under the action of the stream, and of the sun and rain in the warm season when the channel is laid dry. The waters of the Ohio, when I visited the spot in April, 1846, were more than

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* De Verneuil, Bulletin, 4. 678., 1847. D. Sharpe, Quart. Journ. Geol. Soc. vol. iv. pp. 145., 1847.

40 feet below their highest level, and 20 feet above their lowest, so that large spaces of bare rock were exposed to view.*

No less than 46 species of British Devonian corals are described in the Monograph published in 1853 by Messrs. M. Edwards and Jules Haime (Paleontographical Society), and only six of these occur in America; a fact, observes Prof. E. Forbes, which, when we call to mind the wide latitudinal range of the Anthozoa, has an important bearing on the determination of the geography of the northern hemisphere during the Devonian epoch. We must also remember that the corals of these ancient reefs, whether American or European, however recent may be their aspect, all belong to the *Zoantharia rugosa*, a suborder which, as before stated (p. 407. *et seq.*), has no living representative. Hence great caution must be used in admitting all inductions drawn from the presence and forms of these zoophytes, respecting the prevalence of a warm or tropical climate in high latitudes at the time when they flourished, — for such inductions, says Prof. E. Forbes, have been founded "on the mistaking of analogies for affinities." †

This calcareous division also contains *Goniatites*, *Spirifers*, *Pentremites*, and many other genera of Mollusca and Crinoidea, corresponding to those which abound in the Devonian of Europe, and some few of the forms are the same. But the difficulty of deciding on the exact parallelism of the New York subdivisions, as above enumerated, with the members of the European Devonian, is very great, so few are the species in common. This difficulty will best be appreciated by consulting the critical essay published by Mr. Hall in 1851, on the writings of European authors on this interesting question.‡ Indeed we are scarcely as yet able to decide on the parallelism of the principal groups even of the north and south of Scotland, or on the agreement of these again with the Devonian and Rhenish subdivisions.

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* Lyell's Second Visit to the United States, vol. ii. p. 277.

† Geol. Quart. Journ. vol. x. p. lx., 1854.

‡ Report of Foster and Whitney on Geol. of L. Superior, p. 302., Washington, 1851.

CHAPTER XXVII.

SILURIAN AND CAMBRIAN GROUPS.

Silurian strata formerly called Transition — Term Grauwacké — Subdivisions of Upper, Middle, and Lower Silurians — Ludlow formation and fossils — Ludlow bone-bed, and oldest known remains of fossil fish — Wenlock formation, corals, cystideans, trilobites — Middle Silurian or Caradoc sandstone — Its unconformability — Pentameri and Tentaculites — Lower Silurian rocks — Llandeilo flags — Cystideæ — Trilobites — Graptolites — Vast thickness of Lower Silurian strata in Wales — Foreign Silurian equivalents in Europe — Ungulite grit of Russia — Silurian strata of the United States — Amount of specific agreement of fossils with those of Europe — Canadian equivalents — Deep-sea origin of Silurian strata — Fossiliferous rocks below the Llandeilo beds — Cambrian group — Lingula flags of North Wales — Lower Cambrian — Oldest known fossil remains — "Primordial group" of Bohemia — Characteristic trilobites — Metamorphosis of trilobites — Alum schists of Sweden and Norway — Potsdam sandstone of United States and Canada — Footprints near Montreal — Trilobites on the Upper Mississippi — Supposed period of invertebrate animals — Upper Silurian bone-bed — Absence of fish in Lower Silurian — Progressive discovery of vertebrata in older rocks — Inference to be drawn from the greater success of British Paleontologists — Doctrine of the non-existence of vertebrata in the older fossiliferous periods premature.

WE come next in the descending order to the most ancient of the primary fossiliferous rocks, that series which comprises the greater part of the strata formerly called "transition" by Werner, for reasons explained in Chap VIII., pp. 91. and 93. Geologists were also in the habit of applying to these older strata the general name of "grauwacké," by which the German miners designate a particular variety of sandstone, usually an aggregate of small fragments of quartz, flinty slate (or Lydian stone), and clay-slate cemented together by argillaceous matter. Far too much importance has been attached to this kind of rock, as if it belonged to a certain epoch in the earth's history, whereas a similar sandstone or grit is found in the Old Red, and in the Millstone Grit of the Coal, and sometimes in certain Cretaceous and even Eocene formations in the Alps.

The name of *Silurian* was first proposed by Sir Roderick Murchison for a series of fossiliferous strata lying below the Old Red Sandstone, and occupying that part of Wales and some contiguous counties of England which once constituted the kingdom of the *Silures*, a tribe of ancient Britons. The following table will explain the various formations into which this group of ancient strata may be subdivided.

UPPER SILURIAN ROCKS.

		Prevailing Lithological characters.	Thickness in Feet.	Organic remains.
1. Ludlow formation.	Upper Ludlow.	a. *Tilestones.*—Finely laminated reddish and green micaceous sandstones.	800 ?	Marine mollusca of almost every order, the Brachiopoda most abundant. Serpulites. Crustaceans of the Trilobite family. Placoid fish (oldest remains of fish yet known). Sea-weeds; and in the uppermost strata land plants.
		b. Micaceous grey sandstone and mudstone.	2000	
	Aymestry limestone.	Argillaceous limestone.		
	Lower Ludlow.	Shale, with concretions of limestone.		
2. Wenlock formation.	Wenlock limestone.	Concretionary and thick-bedded limestone.	Above 2000	Marine mollusca of various orders as before. Crinoidea and corals plentiful. Trilobites, Graptolites.
	Wenlock shale.	Argillaceous shale, frequently flagstone.		

MIDDLE SILURIAN ROCKS.

Caradoc formation.	Caradoc sandstones.	Shale, shelly limestone, sandstone, and conglomerate.	2000	Crinoidea, Corals, Mollusca, chiefly Brachiopoda. (The genus Pentamerus abundant.)

LOWER SILURIAN ROCKS.

Llandeilo formation.	Llandeilo flags.	Dark coloured calcareous flags; slates and sandstones.	20,000	Mollusca, Trilobites, Cystideæ, Crinoids, Corals, Graptolites.

UPPER SILURIAN ROCKS.

Ludlow formation.—This member of the Upper Silurian group, as will be seen by the above table, is of great thickness, and subdivided into three parts,—the Upper and the Lower Ludlow, and the intervening Aymestry limestone. Each of these may be distinguished near the town of Ludlow, and at other places in Shropshire and Herefordshire, by peculiar organic remains.

1. *Upper Ludlow.* a. *Tilestones.*—This uppermost subdivision, called the *Tilestones,* was originally classed by Sir R. Murchison with the Old Red Sandstone, because they decompose into a red soil throughout the Silurian region. They were regarded as a transition group forming a passage from Silurian to Old Red; but it is now ascertained that the fossils agree in great part specifically, and in general character entirely, with those of the underlying Silurian

strata. Among these are *Orthoceras bullatum, Trochus? helicites, Bellerophon trilobatus, Chonetes lata,* &c., with numerous defences of fishes. These beds are well seen at Kington in Herefordshire, and at Downton Castle near Ludlow, where they are quarried for building.

b. *Grey Sandstone, &c.*—The next subdivision of the Upper Ludlow consists of grey calcareous sandstone, or very commonly a micaceous stone, decomposing into soft mud, and contains, besides the shells just quoted, the *Lingula cornea,* which is common to it and the Tilestone beds. The *Orthis orbicularis,* a round variety of *O. elegantula,* is characteristic of the Upper Ludlow; and the lowest or mudstone beds are loaded for a thickness of 30 feet with *Athyris navicula* (fig. 568.). As usual in strata of the Primary periods, the brachiopodous mollusca predominate over the lamellibranchiate; but the latter are by no means unrepresented. Among other genera, for example, we observe *Avicula* (or *Pterinea*), *Cardiola, Nucula, Sanguinolites,* and *Modiola.*

Fig. 567

Orthis elegantula, Dalm. Var. *orbicularis,* J. Sow. Delbury.
Upper Ludlow.

Fig. 568.

Athyris (Terebratula) navicula, J. Sow.
Aymestry limestone; also in
Upper and Lower Ludlow.

Some of the Upper Ludlow sandstones are ripple-marked, thus affording evidence of gradual deposition; and the same may be said of the accompanying fine argillaceous shales which are of great thickness, and have been provincially named "mudstones." In some of these shales stems of crinoidea are found in an erect position, having evidently become fossil on the spots where they grew at the bottom of the sea. The facility with which these rocks, when exposed to the weather, are resolved into mud, proves that, notwithstanding their antiquity, they are nearly in the state in which they were first thrown down.

The *bone-bed* of the Upper Ludlow deserves especial notice as affording the oldest well-authenticated example of the fossil remains of fish. It usually consists of a single thin layer of brown bony fragments near the junction of the Old Red Sandstone and the Ludlow rocks, and was first observed by Sir R. Murchison, near the town of Ludlow, where it is three or four inches thick. It has since been traced to a distance of 45 miles from that point into Gloucestershire and other counties, and is commonly not more than an inch thick. At May Hill two bone-beds were observed, with 14 feet of intervening strata full of Upper Ludlow fossils.* At that point immediately above the upper fish-bed

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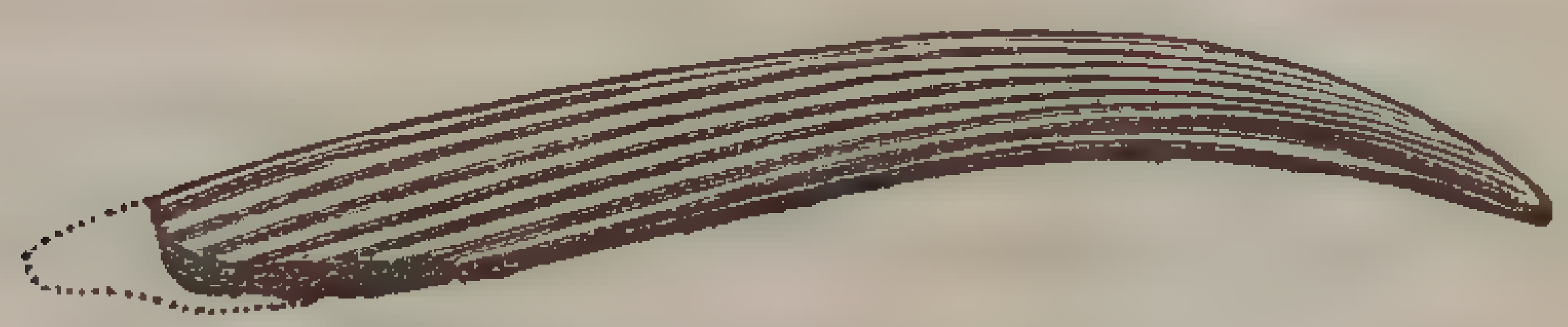
* Murchison's Siluria, pp. 137—237.

numerous globular bodies were found, which were determined by Dr. Hooker to be the spores of a cryptogamic land-plant, probably Lycopodiaceous. These beds occur just beneath the lowest strata of the "Old Red." Some of the fish are of the shark family, and their defences are referred to the genus *Onchus* (fig. 569.). There are also numerous minute shagreen scales (fig. 570.), which may possibly belong to the same placoid fish. The jaw and teeth of another predaceous genus (fig. 571.) have also been detected. As usual in bone-beds, the teeth and bones are, for the most part, fragmentary and rolled. Many statements have been published of fish remains obtained from older members of the Silurian series; but Mr. Salter has shown all these to be spurious.* Professor Phillips has, however, discovered fish-bones at the bottom of the "Upper Ludlow," at its junction with the Aymestry Rock †; and lower than this no one seems as yet to have succeeded in tracing them downwards, whether in Europe or North America, for M. Barrande's most ancient ichthyolites (bony fragments, 8 inches long) occur in the Upper Silurian of Bohemia; and those of the American geologists are from the Oriskany Sandstone, a formation which is still considered as debateable ground between the Devonian and Silurian systems (see p. 430. above).

Fig. 569.



Onchus tenuistriatus, Agass.
Bone-bed. Upper Silurian; Ludlow.

Fig. 570.

Shagreen-scales of a placoid fish (*Thelodus*).
Bone-bed. Upper Ludlow.

Fig. 571.

Plectrodus mirabilis, Agass.
Bone-bed. Upper Ludlow.

In England it is true, as in the United States and Canada, globular, cylindrical, or flattened masses have been detected, composed principally of phosphate of lime, in the Lowest Silurian rocks, and they have been suspected to be coprolitic. Messrs. Logan and Hunt have recently shown that shells of the genera *Lingula* and *Orbicula*, which occur abundantly in the same formations, are also made up of phosphate and carbonate of lime, mixed in the like proportions; and it has been suggested that the decomposition of such shells might give rise to the nodules alluded to which may owe their form to concretionary action.‡ Even if the zoologist should think it more likely that the phosphatic matter was rejected in fæcal lumps, by creatures feeding on Lingulæ and Orbiculæ, we cannot decide that such feeders were of the vertebrate class, rather than Cephalopods, Crustaceans, or some other of the Invertebrata. In regard to the doctrine of the supposed non-existence of fish in the Silurian seas before the time of the Ludlow bone-bed, I shall consider that question fully in the concluding pages of this chapter, p. 457., *et seq.*

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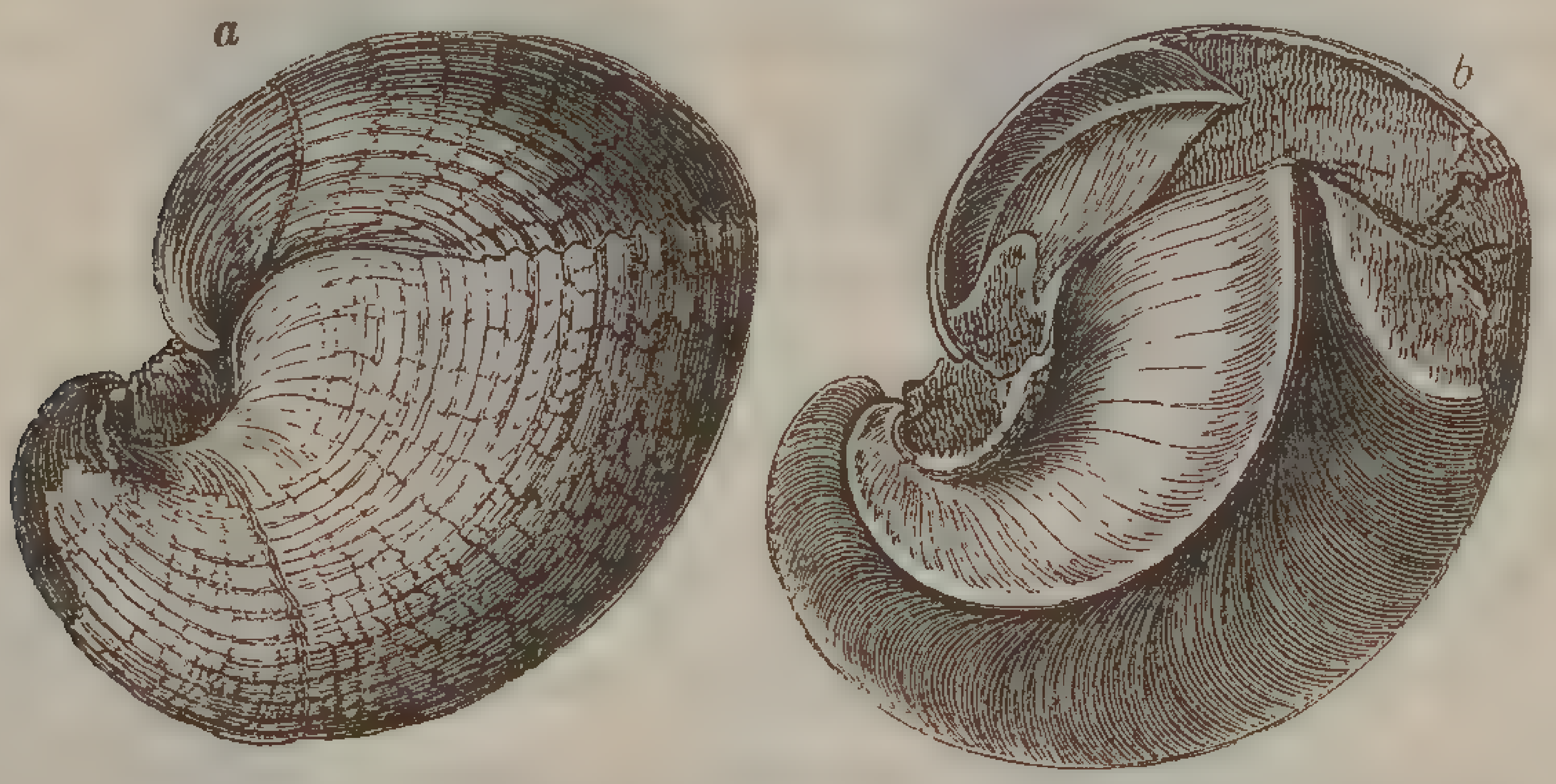
* Geol. Quart. Journ. vol. vii. p. 263

† Memoirs Geol. Surv. vol ii.

‡ Logan and Hunt; Silliman's Journ. No. 50. 2d series, March 1854.

2. *Aymestry limestone.* — The next group is a subcrystalline and argillaceous limestone, which is in some places 50 feet thick, and distinguished around Aymestry by the abundance of *Pentamerus Knightii*, Sow. (fig. 572.), also found in the Lower Ludlow. This genus of brachiopoda was first found in Silurian strata, and is exclusively a paleozoic form. The name was derived from πεντε, *pente*, five, and μερος, *meros*, a part, because both valves are divided by a central septum, making four chambers, and in one valve the septum itself contains a small chamber, making five. The size of these septa is enormous compared with those of any other brachiopod shell; and they must nearly have divided the animal into two equal halves; but they are, nevertheless, of the same nature as the septa or plates which are found in the interior of *Spirifer*, *Terebratula*, and many other shells of this order. Messrs. Murchison and De Verneuil discovered this species dispersed in myriads through a white limestone of Upper Silurian age, on the banks of the Is, on the eastern flank of the Urals in Russia, and a similar species is frequent in Sweden.

Fig. 572.



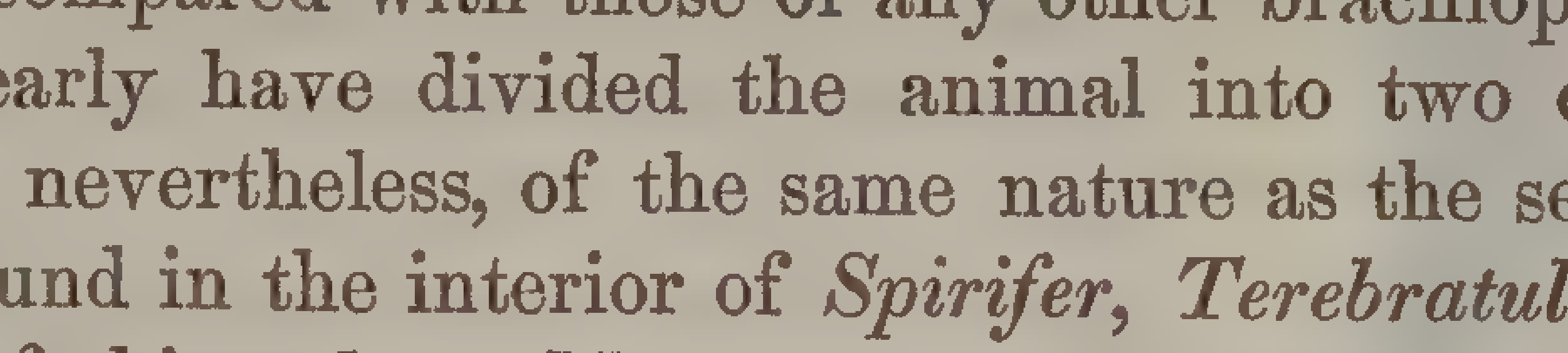
Pentamerus Knightii, Sow. Aymestry. Half nat. size.
a. view of both valves united.
b. longitudinal section through both valves, showing the central plates or septa.

Three other abundant shells in the Aymestry limestone are, 1st, *Lingula Lewisii* (fig. 573.); 2d, *Rhynchonella Wilsoni*, Sow. (fig. 574.), which is also common to the Lower Ludlow and Wenlock limestone; 3d, *Atrypa reticularis*, Lin. (fig. 575.), which has a very wide range, being found in every part of the Silurian system, even in the upper portion of the Llandeilo flags.

Fig. 573.

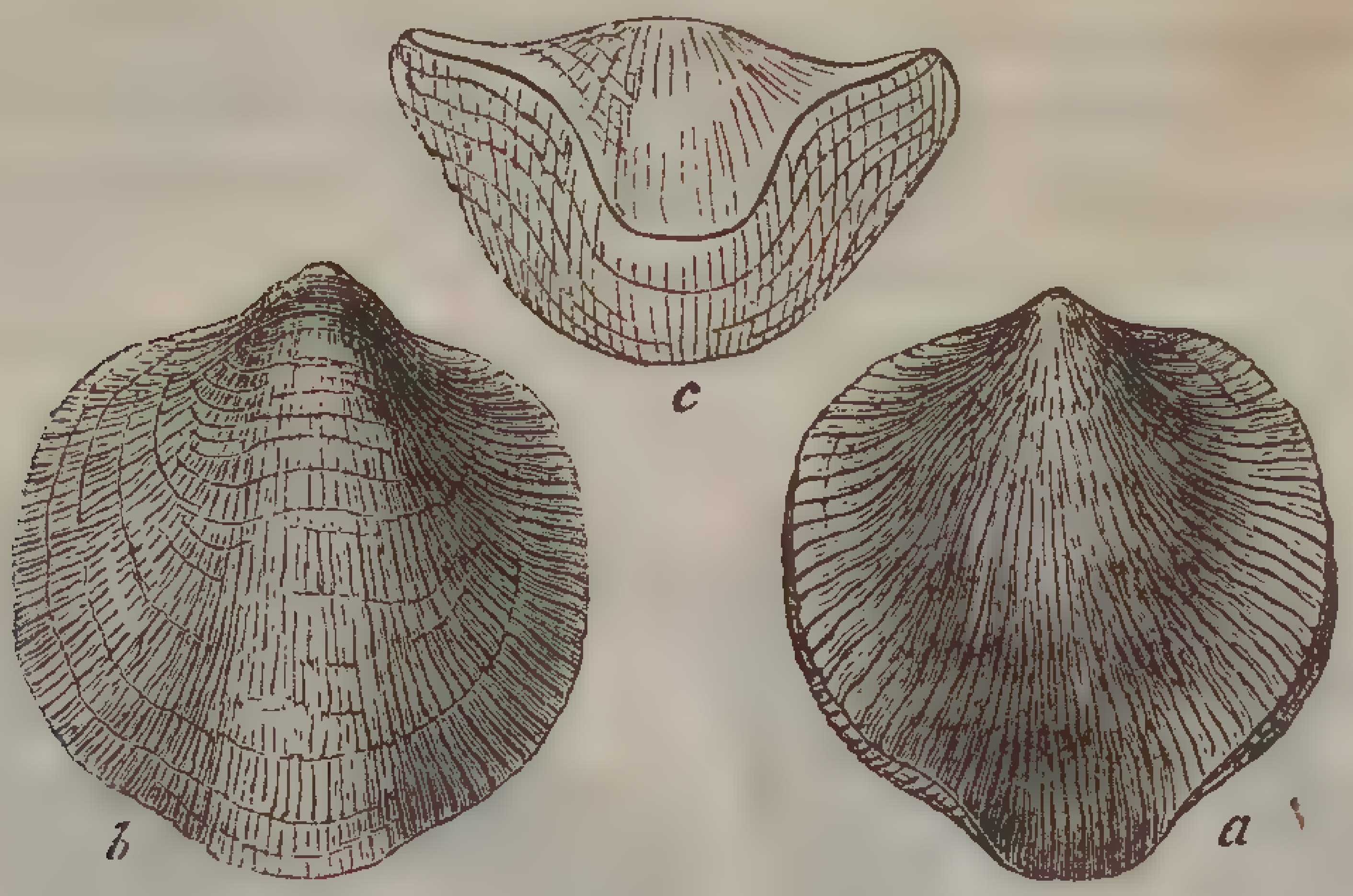
Lingula Lewisii, J. Sow. Abberley Hills.

Fig. 574.



Rhynchonella (*Terebratula*) *Wilsoni*, Sow. Aymestry.

Fig. 575.



Atrypa reticularis, Linn. (*Terebratula affinis*, Min. Con.) Aymestry.
a. upper valve. *b.* lower valve.
c. anterior margin of the valves.

The Aymestry Limestone contains so many shells, corals, and trilobites agreeing specifically with those of the subjacent Wenlock limestone, that it is scarcely distinguishable from it by its fossils alone. Nevertheless, many of the organic remains are common to the Aymestry limestone and the Upper Ludlow, and several of these are not found in the Wenlock.*

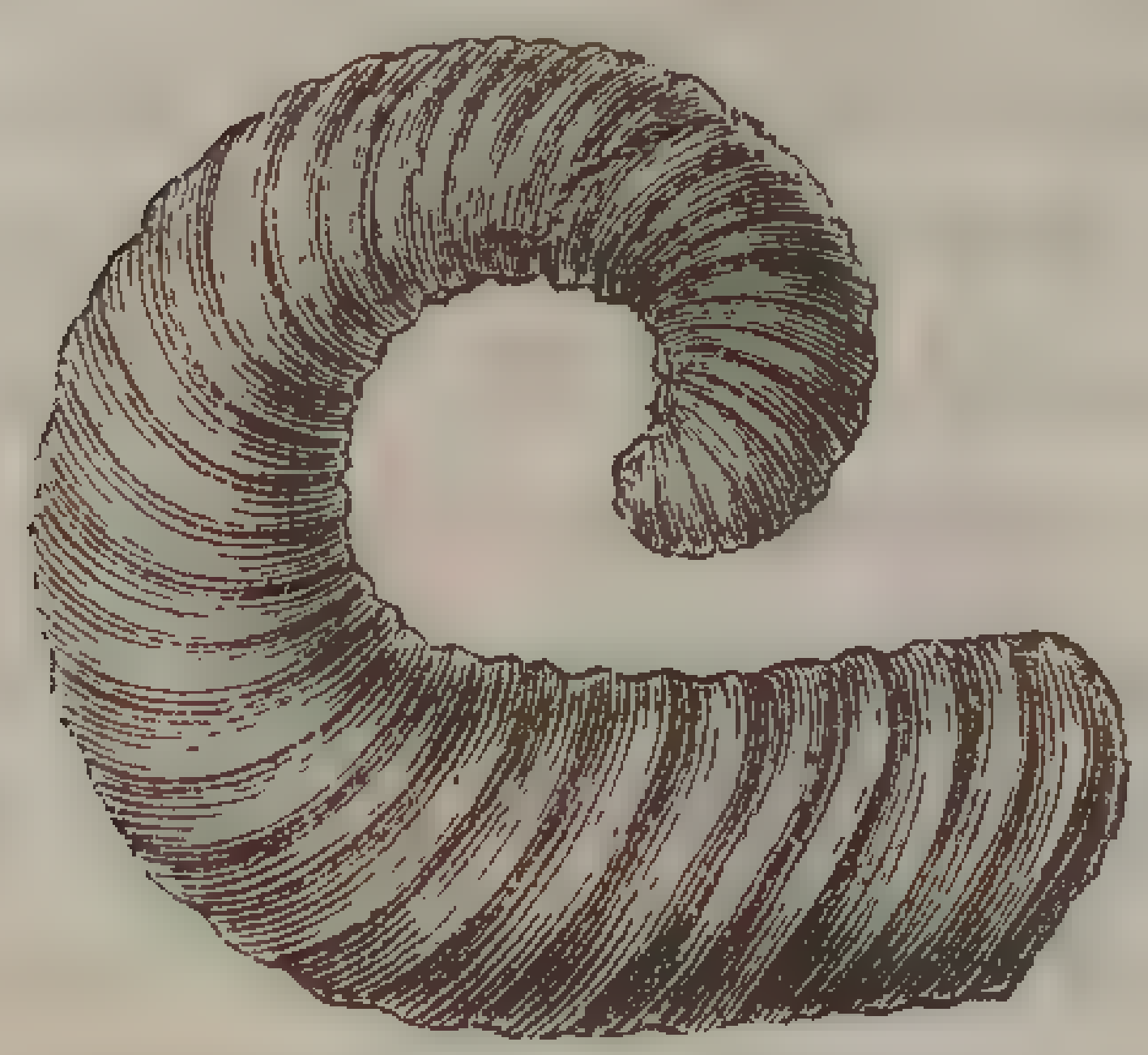
Fig. 576.

Phragmoceras ventricosum, J. Sow. (*Orthoceras ventricosum*, Stein.) Aymestry; ½ nat. size.

3. *Lower Ludlow shale.*—This mass is a dark grey argillaceous deposit, containing, among other fossils, many large chambered shells of genera scarcely known in newer rocks, as the *Phragmoceras* of Broderip, and the *Lituites* of Breyn (see figs. 576, 577.). The latter is partly straight and partly convoluted, nearly as in *Spirula*.

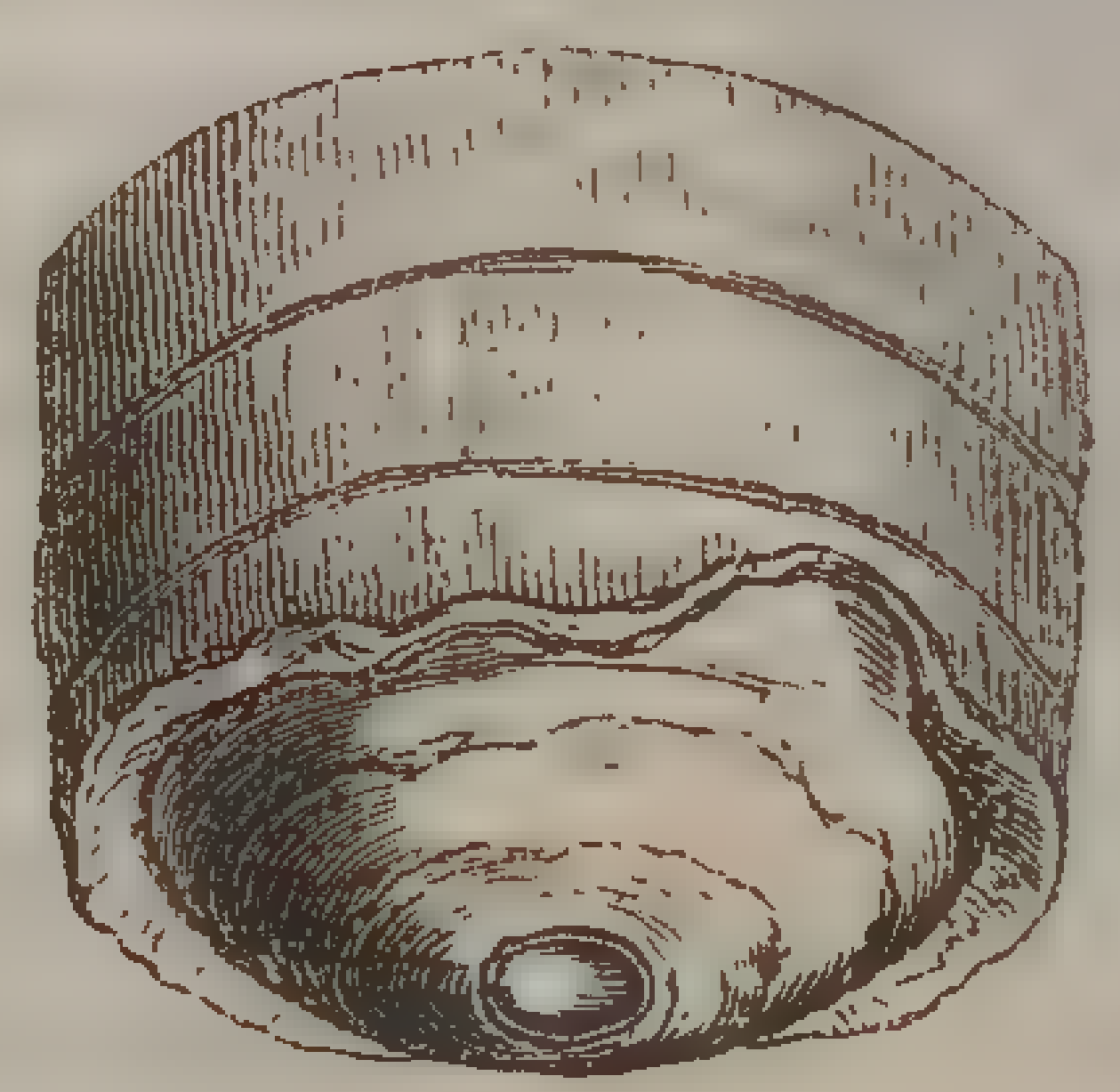
The *Orthoceras Ludense* (fig. 578.), as well as the cephalopod last mentioned, is peculiar to this member of the series.

Fig. 577.



Lituites giganteus, J. Sow.
Near Ludlow; also in the Aymestry and Wenlock limestones; ½ nat. size.

Fig. 578.



Fragment of *Orthoceras Ludense*, J. Sow.
Leintwardine, Shropshire.

A species of Graptolite, *G. Ludensis*, Murch. (fig. 588., p. 441.), a form of zoophyte which has not yet been met with in strata above the Silurian, occurs plentifully in the Lower Ludlow.

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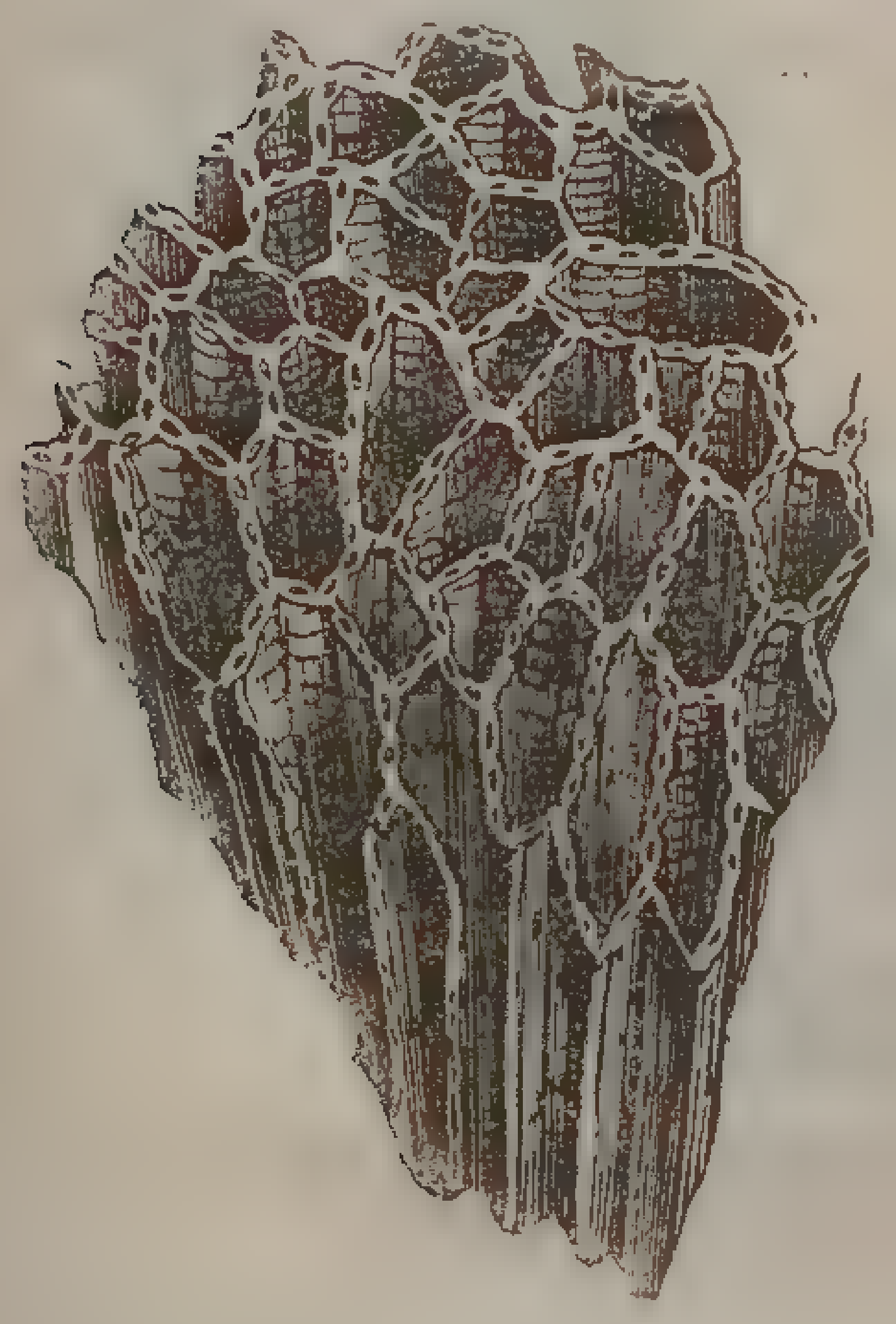
* Murchison's Siluria, p. 133.

Wenlock formation.—We next come to the Wenlock formation, which has been divided (see Table, p. 434.) into the Wenlock limestone and the Wenlock shale.

1. The Wenlock limestone, formerly well known to collectors by the name of the Dudley limestone, forms a continuous ridge in Shropshire, ranging for about 20 miles from S.W. to N.E., about a mile distant from the nearly parallel escarpment of the Aymestry limestone. This ridgy prominence is due to the solidity of the rock, and to the softness of the shales above and below it. Near Wenlock it consists of thick masses of grey subcrystalline limestone, replete with corals and encrinites. It is essentially of a concretionary nature; and the concretions, termed "ball-stones" in Shropshire, are often enormous, even 80 feet in diameter. They are of pure carbonate of lime, the surrounding rock being more or less argillaceous.* Sometimes in the Malvern Hills this limestone, according to Professor Phillips, is oolitic.

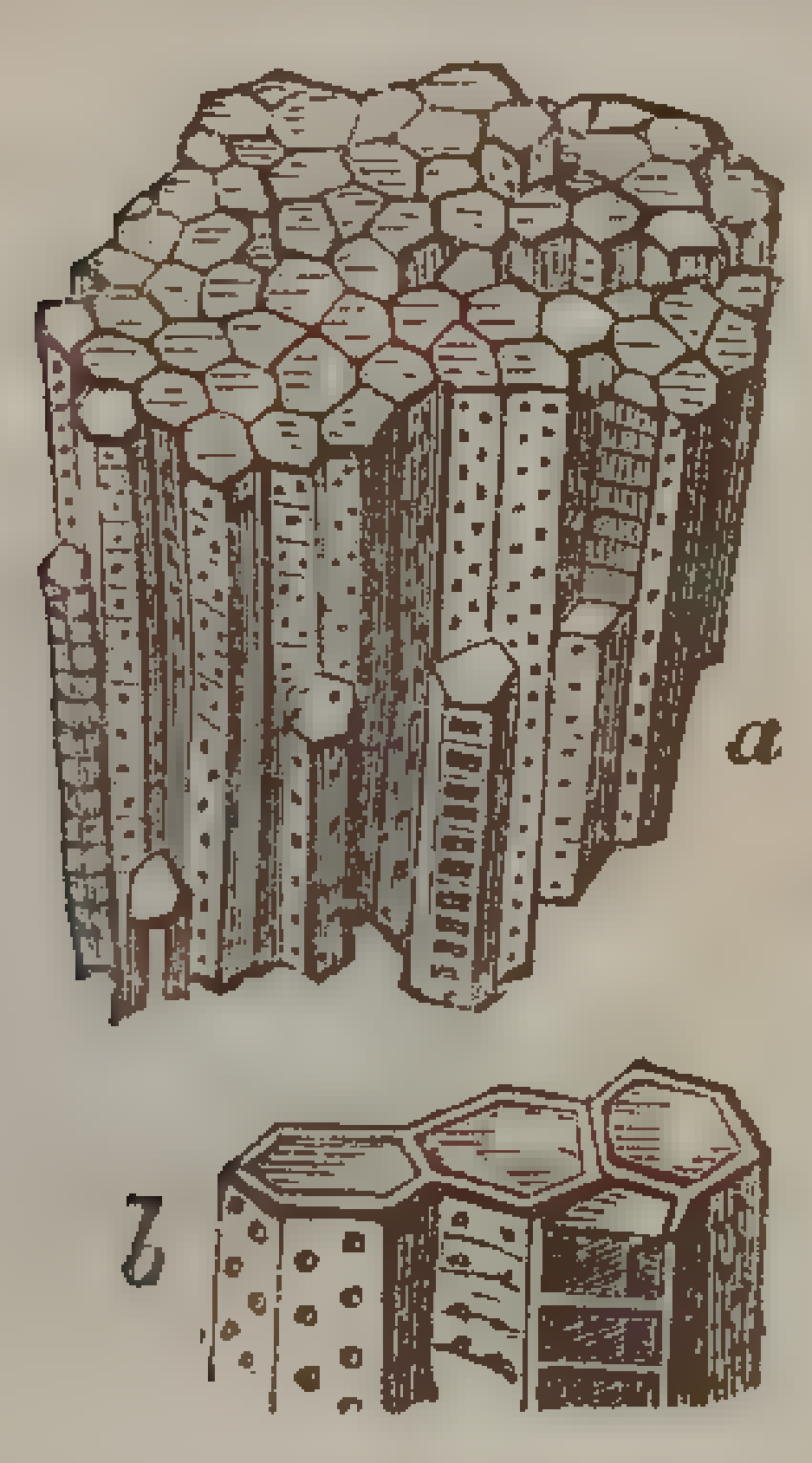
Fig. 579.



Halysites catenulatus, Linn. sp.
Syn. *Catenipora escharoides*, Gold.
Upper and Lower Silurian.

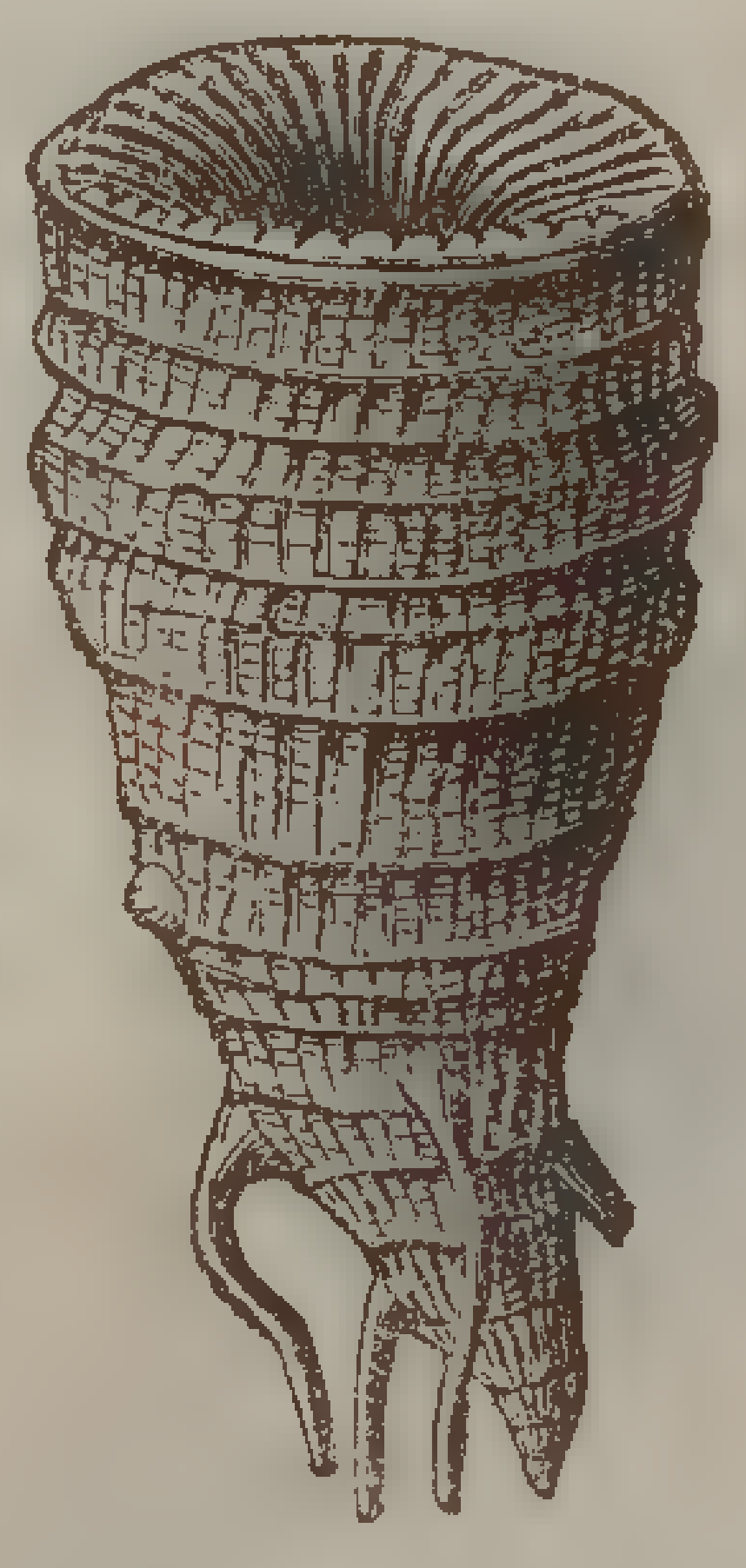
Among the corals in which this formation is so rich, the "chain-coral," *Halysites catenulatus*, or *Catenipora escharoides* (fig. 579.), may be pointed out as one very easily recognized, and widely spread in Europe, ranging through all parts of the Silurian group, from the Aymestry limestone to near the bottom of the series. Another coral, the *Favosites Gothlandica* (fig. 580.), is also met with in profusion in large hemispherical masses, which break up into prismatic fragments, like that here figured (fig. 580.). Another common form in the Wenlock limestone is the *Omphyma* (fig. 581.), which, like many of its companions, reminds us of some modern cup-corals, but all the Silurian genera belong to the paleozoic type before-mentioned

Fig. 580.



Favosites Gothlandica, Lam. Dudley.
a. portion of a large mass; less than the natural size.
b. magnified portion to show the pores and the partitions in the tubes.

Fig. 581.



Omphyma turbinatum, Linn. sp.
(*Cyathophyllum*, Goldf.)
Wenlock Limestone, Shropshire.

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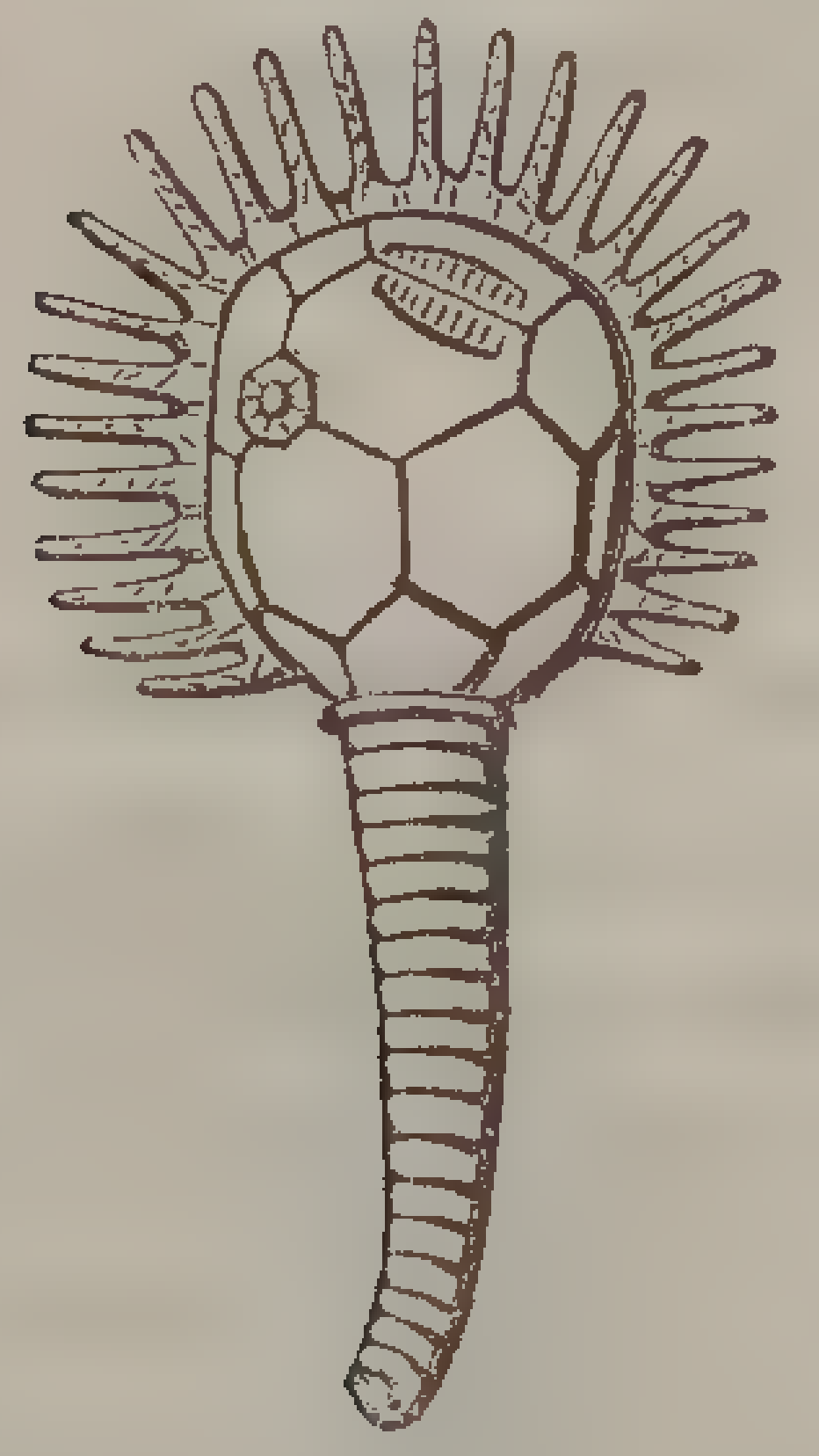
* Murchison's Siluria, p. 115.

(p. 407.), exhibiting the quadripartite arrangement of the lamellæ within the cup.

Among the numerous Crinoids, several peculiar species of *Cyathocrinus* (for genus, see figs. p. 409.) contribute their calcareous stems, arms, and cups towards the composition of the Wenlock limestone. Of Cystideans there are a few very remarkable forms, some of them peculiar to the Upper Silurian formation, as for example the *Pseudocrinites*, which was furnished with pinnated fixed arms*, as represented in the annexed figure (fig. 582.).

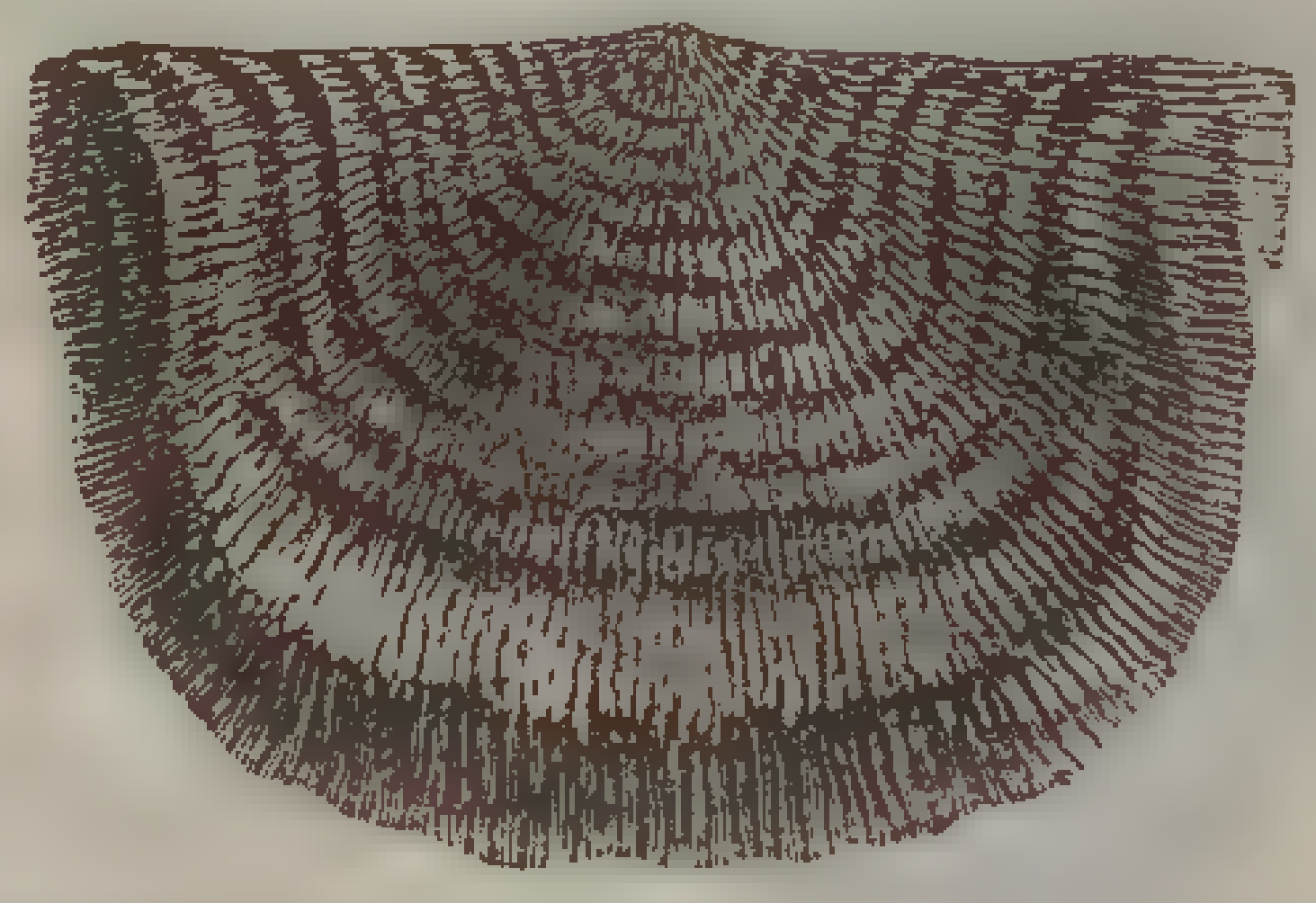
The Brachiopoda are for the most part of the same species as those of the Aymestry limestone; as, for example, *Atrypa reticularis* (fig. 575., p. 438.), and *Strophomena depressa*, Sow. sp. (fig. 583.); but these species range also through the Ludlow rocks, Wenlock shale, and Caradoc Sandstone.

Fig. 582.



Pseudocrinites bifasciatus, Pearce.
Wenlock Limestone, Dudley.

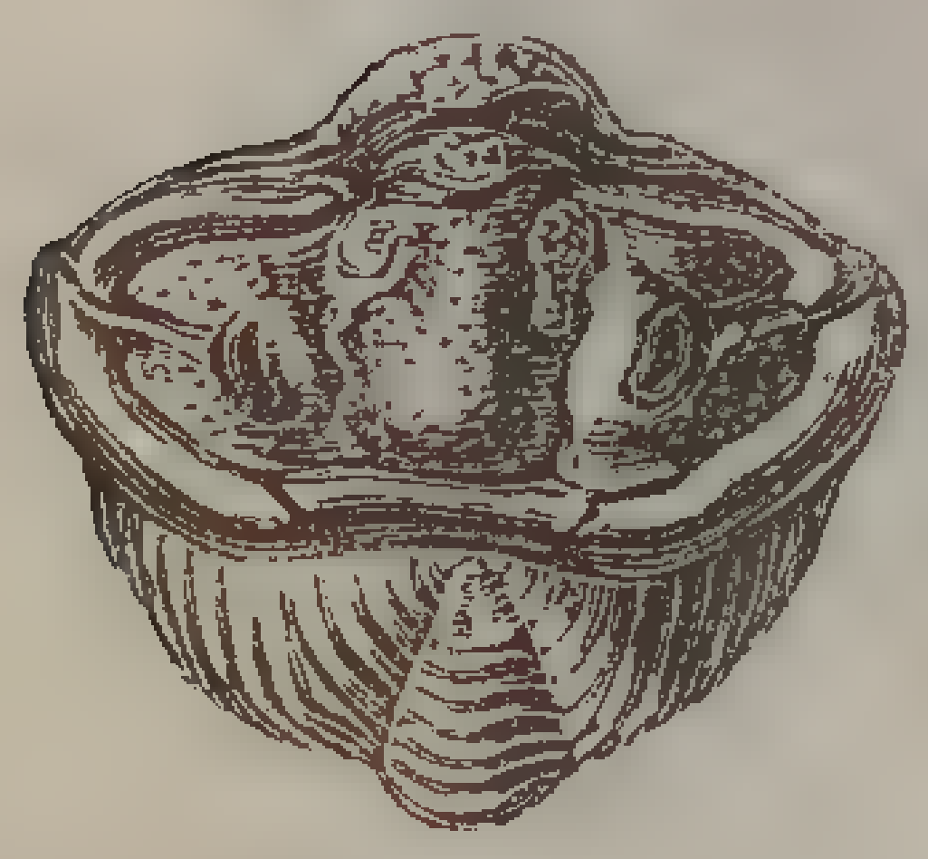
Fig. 583.



Strophomena (Leptæna) depressa, Sow.
Wenlock and Ludlow Rocks.

The Crustaceans are represented almost exclusively by Trilobites, which are very conspicuous. The *Calymene Blumenbachii*, called the "Dudley Trilobite," was known to collectors long before its true place in the animal kingdom was ascertained. It is often found coiled up like the common *Oniscus* or wood-louse, and this is so common a circumstance among the trilobites as to lead us to conclude that they must have habitually resorted to this mode of protecting themselves when alarmed. *Sphærexochus mirus* (fig. 586.)

Fig. 584.



Calymene Blumenbachii, Brong.
Wenlock, Ludlow, and Aymestry limestones.

Fig. 585.

Phacops caudatus, Brong.
Wenlock, Aymestry, and Ludlow Rocks.

Fig. 586.

Sphærexochus mirus, Beyrich.
coiled up.
Dudley; also in Ohio, N. America.

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* E. Forbes, Mem. Geol. Survey, vol. ii. p. 496.

is almost a globe when rolled up, the forehead of this species being extremely inflated. The *Homalonotus*, a form of Trilobite in which the tripartite division of the dorsal crust is almost lost (see fig. 587.), is very characteristic of this division of the Silurian series.

Fig. 587.

Homalonotus delphinocephalus, Konig. Dudley Castle; ½ nat. size.

2. *The Wenlock Shale.*—This, observes Sir R. Murchison *, is infinitely the largest and most persistent member of the Wenlock formation, for the limestone often thins out and disappears. The shale, like the Lower Ludlow, often contains elliptical concretions of impure earthy limestone. In the Malvern district it is a mass of finely levigated argillaceous matter, attaining, according to Prof. Phillips, a thickness of 640 feet, but it is sometimes more than 1000 feet thick in Wales. The prevailing fossils, besides corals and trilobites, and some crinoids, are several small species of *Orthis*, with other brachiopods and certain thin-shelled species of *Orthoceratites.* One species of *Graptolite*, a group of zoophytes before alluded to as being confined to Silurian rocks, is very abundant in this shale, and occurs more sparingly in "the Ludlow." Of these fossils, which are more characteristic of the Lower Silurian, I shall again speak in the sequel (p. 446.).

Fig. 588.

Graptolithus Ludensis, Murchison. Ludlow and Wenlock Shales.

MIDDLE SILURIAN ROCKS.

Caradoc Sandstone.—This sandstone, so named from a mountain called Caer Caradoc, in Shropshire, was originally considered by Sir Roderick Murchison as the sandy and upper portion of the Lower Silurian strata. Subsequent investigations have led to the conclusion that the original or typical Caradoc is divisible into two formations,—the lower, an arenaceous form of the Llandeilo flags, and containing identical species of fossils; the other or superior sandstone, a series of strata resting unconformably on the Llandeilo beds, and chiefly characterized by Upper Silurian fossils, yet having some intermixture of species common to the "Lower Silurian." Hence the Caradoc, as distinct from the Llandeilo, must either be classed as the base of the Wenlock Shale, an opinion to which some authorities incline,—or it may be regarded as a Middle Silurian group, an alternative which I have embraced provisionally in common with many officers of our Government Survey. The larger part, therefore, of what was once termed "the Caradoc" has merged into the Llandeilo, and is the equivalent of the upper and middle portions of that division.

The first step towards placing in a clearer light the relations of "the Caradoc" to the strata above and below it, was made in 1848

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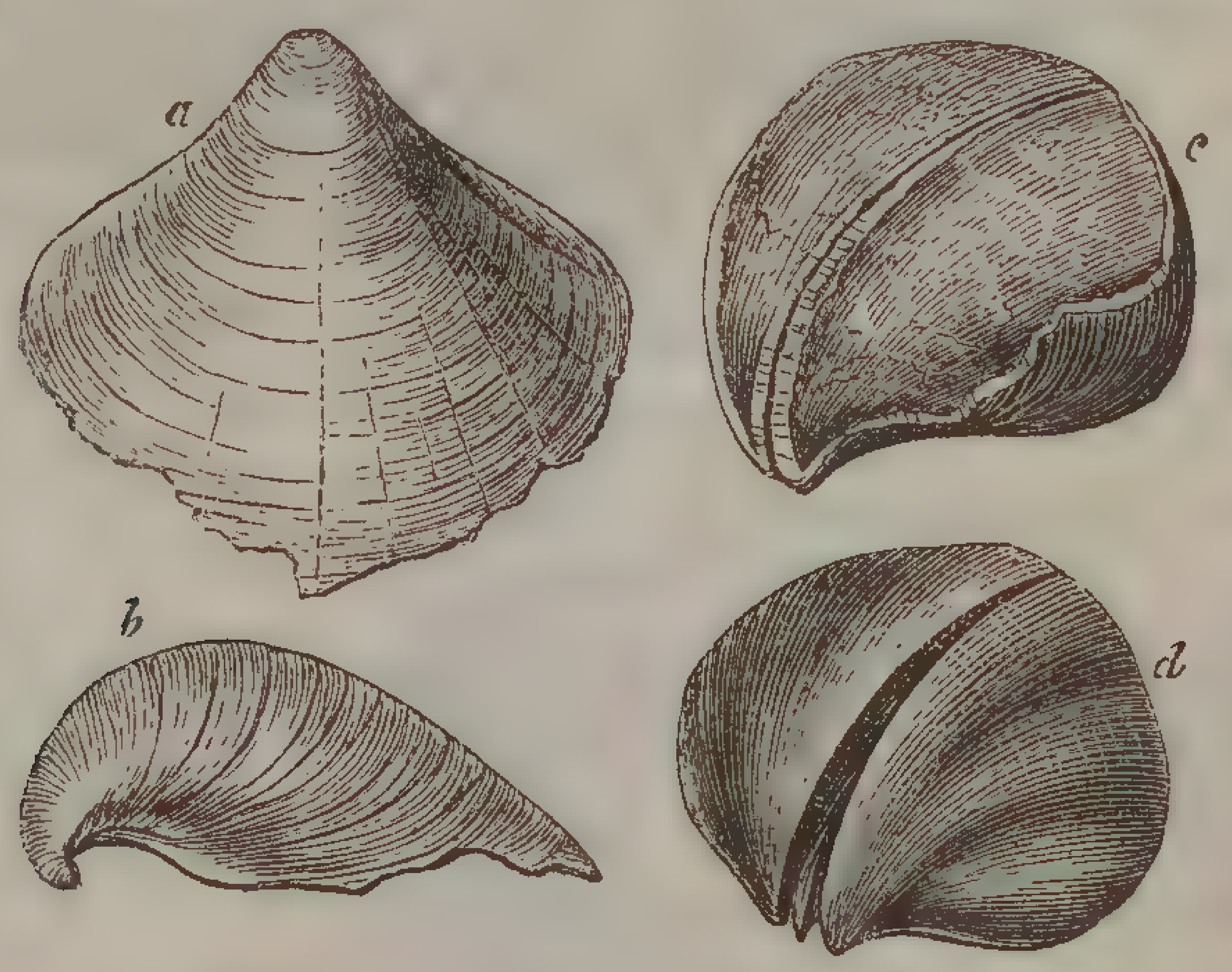
* Siluria, p. 111.

by Professor Ramsay and Mr. Aveline, who observed that in the Longmynd Hills the Caradoc sandstone rested unconformably on the Lower Silurian, and that the latter or "Llandeilo flags," together with some still older rocks, must have constituted an island in the Caradoc sea. Professor E. Forbes at the same time observed that the island was probably high and steep land rising from a deep sea, and that the Caradoc fossils, some of them of littoral aspect, as *Littorina* and *Turritella*, were deposited round the margin of that ancient land. It was also remarked that while the sandstone and conglomerate of this upper Caradoc[*] reposed unconformably on the Llandeilo beds, it at the same time graduated upwards, as Sir R. Murchison had stated, into the Wenlock Shale.

Subsequently Professor Sedgwick and Mr. M'Coy, pursuing their investigations independently of the Survey in North Wales, became convinced[†] that the Caradoc beds of May Hill and the Malverns, constituting the Upper Caradoc, already mentioned, were full of Upper Silurian fossils; and that the strata of Caradoc sandstone at Horderly and other places east of Caer Caradoc belonged to the Bala group (or equivalent of the Llandeilo), being distinguished by Lower Silurian species. This opinion was finally substantiated by Mr. Salter and Mr. Aveline, in 1853, by an appeal to parts of Shropshire where "the Caradoc" had been originally studied by Sir R. Murchison, and where they found the Upper Caradoc unconformable on the lower, and filled with a series of very distinct fossils.[‡]

In the restricted sense, therefore, in which it is now understood, the Caradoc Sandstone comprises a series of beds of passage from the Lower to the Upper Silurian group. It is everywhere characterized by species of *Pentamerus* and *Atrypa* unknown in the overlying Wenlock or Ludlow beds, but which descend into the strata of the Llandeilo group. *Pentamerus lævis* (fig. 589.), and

Fig. 589.



Pentamerus lævis, Sow. Caradoc Sandstone.
Perhaps the young of *Pentamerus oblongus*.

a, *b*. Views of the shell itself, from figures in Murchison's Sil. Syst.
c. Cast with portion of shell remaining, and with the hollow of the central septum filled with spar.
d. Internal cast of a valve, the space once occupied by the septum being represented by a hollow in which is seen a cast of the chamber within the septum.

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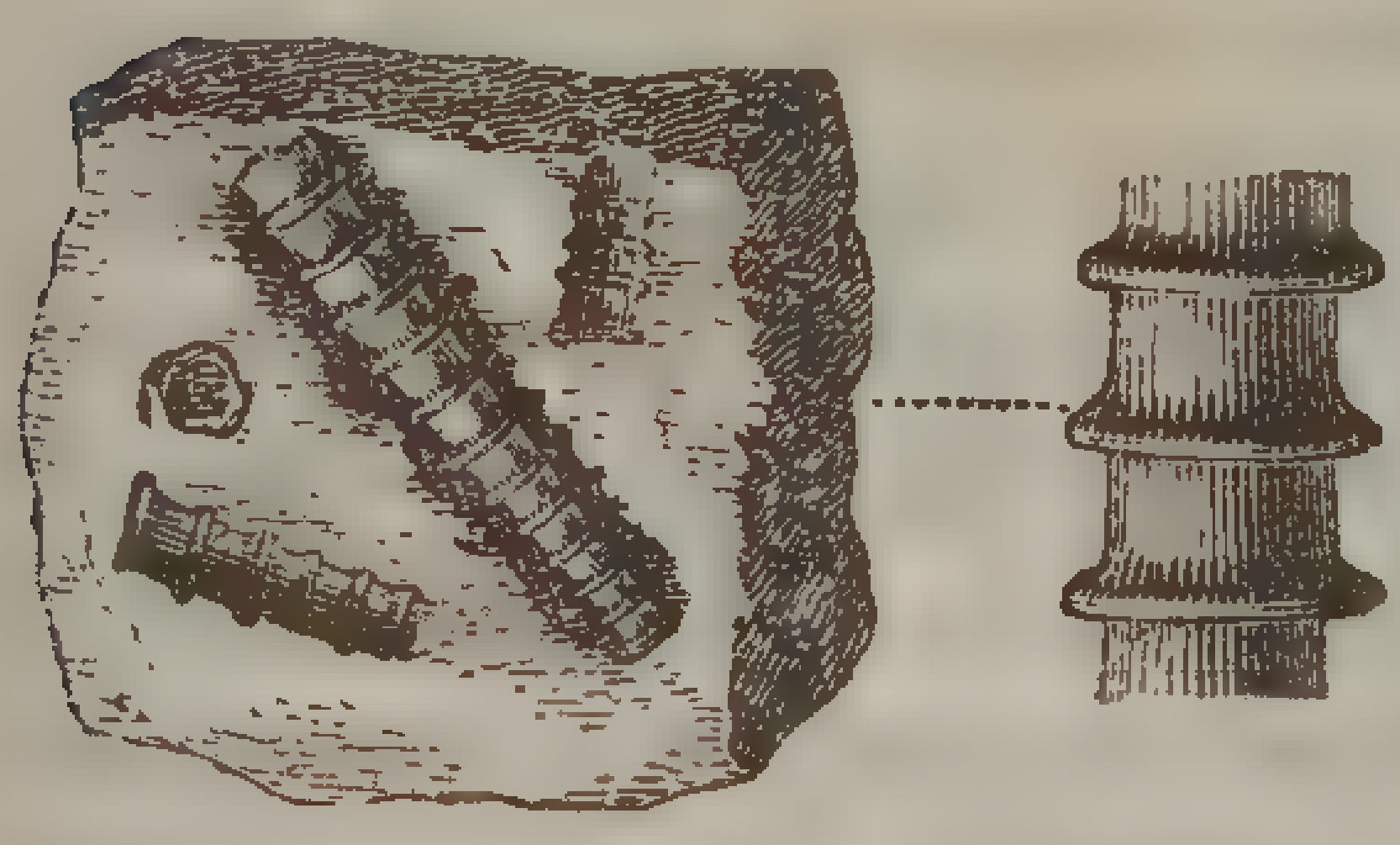
[*] Quart. Geol. Journ., vol. iv. p. 297.

[†] Geol. Quart. Journ., 1852.

[‡] Geol. Quart. Journ., vol. x. p. 62.

P. oblongus may be particularly mentioned as brachiopods which abounded in Siluria, and had a very wide geographical range, being met with in the same place in the Silurian series of Russia and the United States. Among its fossils, too, *Tentaculites annulatus* (fig. 590.), an annelid probably allied to *Serpula,* is exceedingly common. This also is a link to connect it with the Lower rather than the Upper Silurian. All the shelly sandstone of the Malvern and Abberly Hills, of Tortworth in Gloucestershire, and of the centre of the May Hill and Woolhope districts belong to this Middle Silurian, which in the Malvern range attains a thickness of 600 feet. Of the same age are dense masses of sandstone with shale, 2000 feet in thickness, in the higher and disturbed regions of North Wales, as in the Berwyn Mountains for example. According to Professor Sedgwick the hard quartzose Coniston Grits of Westmoreland may also be referred to the same period.

Fig. 590.



Tentaculites annulatus, Schlot.
Interior casts in sandstone.
Eastnor Park; nat. size, and magnified.

LOWER SILURIAN ROCKS.

Llandeilo Flags. — The Lower Silurian strata were originally divided by Sir R. Murchison into an upper group, already described, and termed the Caradoc Sandstone, and a lower one, called, from a town in Caermarthenshire, the *Llandeilo* flags. The strata last mentioned consist of dark-coloured micaceous flags, frequently calcareous, with a great thickness of shales, generally black, below them. The same beds are also seen at Builth in Radnorshire, and here they are interstratified with volcanic matter. Above these typical Llandeilo beds, however, the Lower Silurian contains both in North and South Wales, some strata in which the Pentameri of the Middle Silurian, already alluded to (p. 442.), are associated with species of fossils identical with those in the Llandeilo flags. The corals of the calcareous zone of the Llandeilo belong to the genera *Halysites* (see fig. 579.), *Heliolites*, *Petraia*, *Stenopora*, *Favosites* (fig. 580.), and others *; and there are peculiar Crinoids and Cystideans in the same rocks. These last are amongst the most recent additions made by paleontologists to the *Radiata.* Their structure and relations were first elucidated in an essay published by Von Buch at Berlin in 1845. They are the *Sphæronites* of old authors, and are usually met with as spheroidal bodies covered with polygonal plates, with a mouth on the upper side, and a point of attachment for a stem (which is almost always broken off) on the lower (fig. 591. *b*). They are considered by Professor E. Forbes as intermediate between the crinoids and echinoderms. The Sphæronite here represented (fig. 591.) occurs in the Llandeilo beds in Wales †, as also in Sweden and Russia.

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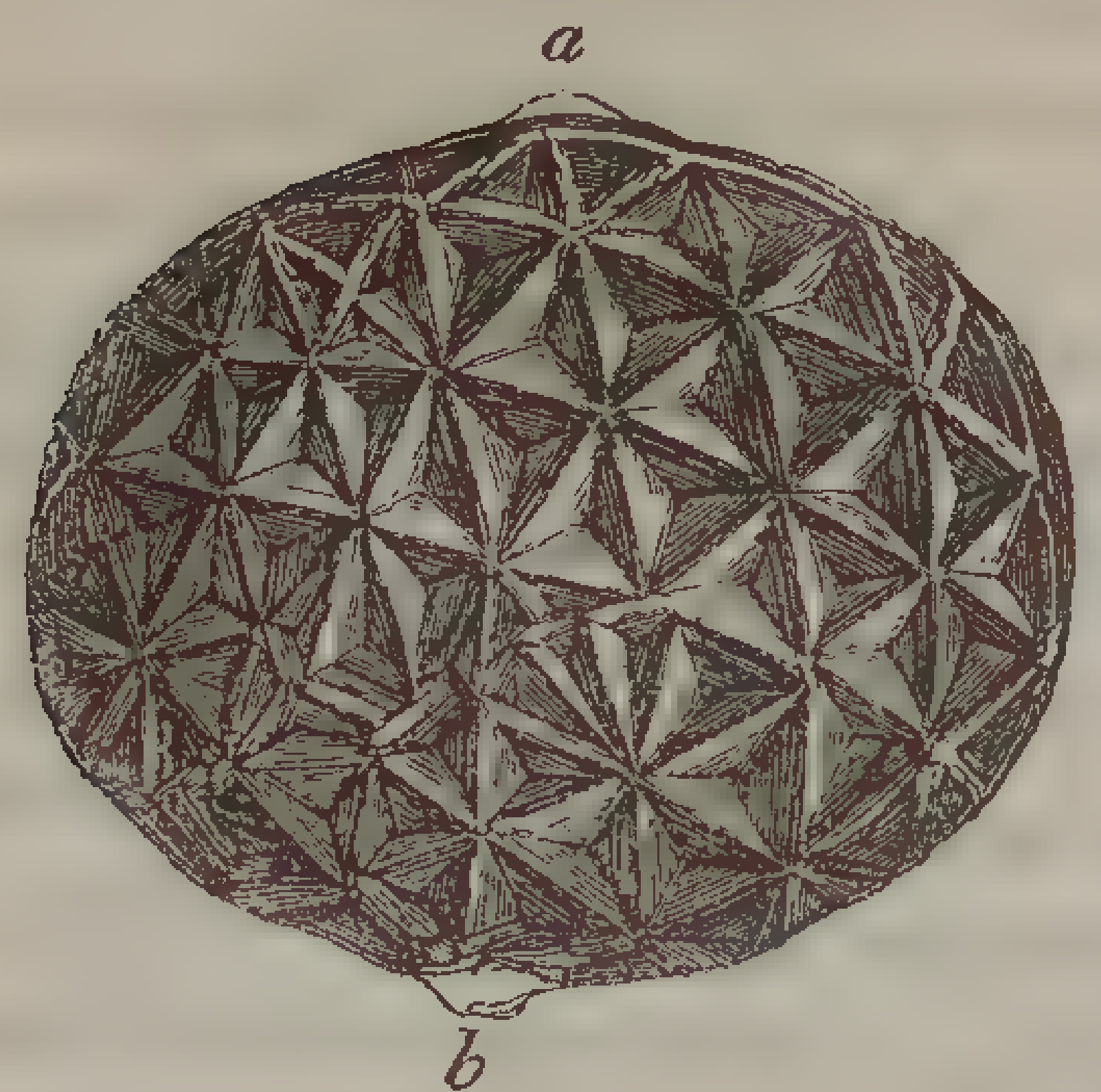
* Murchison's Siluria, p. 178.

† Quart. Geol. Journ. vol. vii. p. 11.; and Mem. Geol. Surv. vol. ii. p. 518.

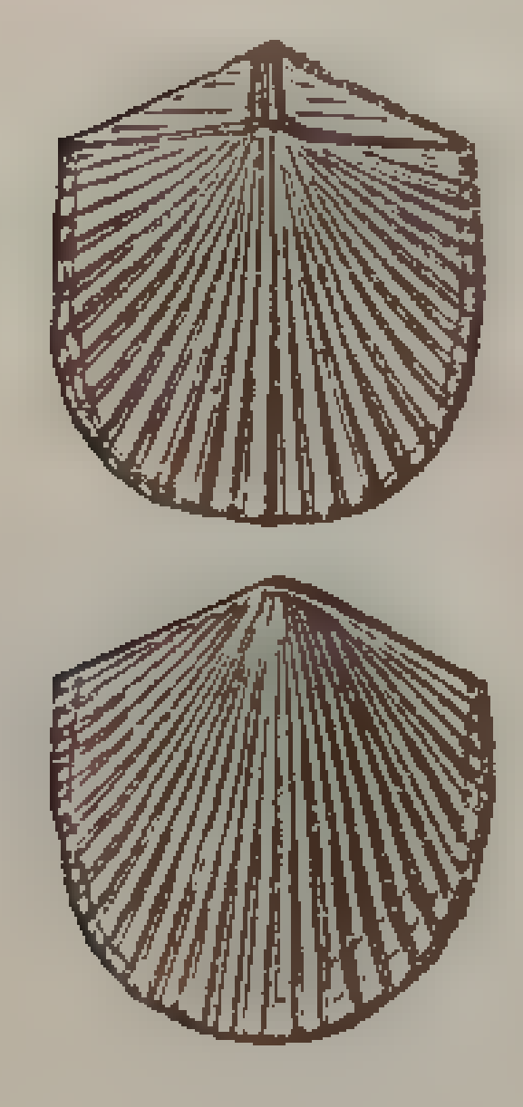
Fig. 591.



Echinosphærites balticus, Eichwald, sp.
(Of the family *Cystideæ*.)
a. mouth
b. point of attachment of stem.
Lower Silurian, S. & N. Wales.

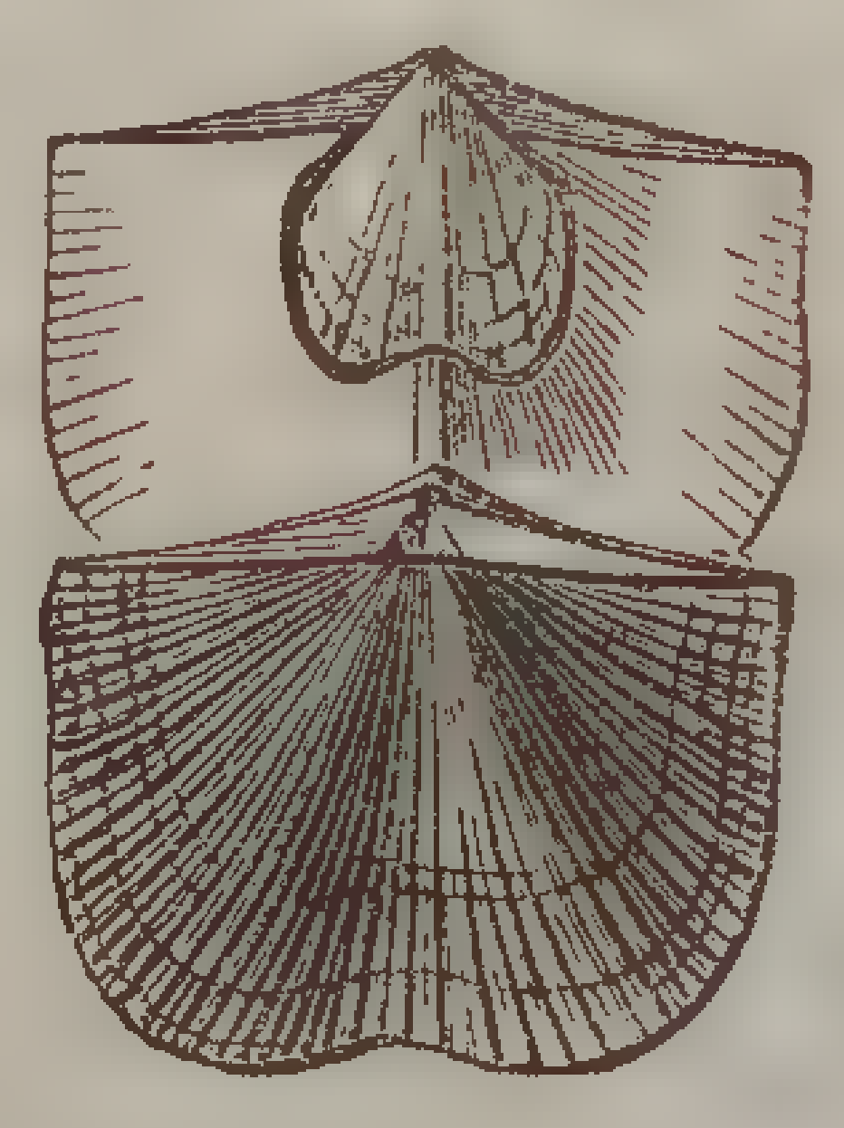
Examples are not wanting, though very rare, of star-fish in the same beds. Brachiopod shells are in the greatest abundance, chiefly of the genera *Orthis*, *Leptæna*, and *Strophomena* (fig. 591.). Of the *Orthides* those species with broad simple ribs (fig. 592.) are particularly characteristic. Such shells as *Atrypa* and *Spirifer*, so frequent in the Upper and Middle Silurian, are rare or confined to the superior part of the Lower Silurian, while *Chonetes* and *Productus* are wholly absent. It is remarkable, however, that *Rhynchonella* and *Lingula*, genera of which there are living representatives in the present seas, were common in the Silurian ocean.

Fig. 592.



Orthis tricenaria, Hall.
New York. Canada.
½ nat. size.

Fig. 593.



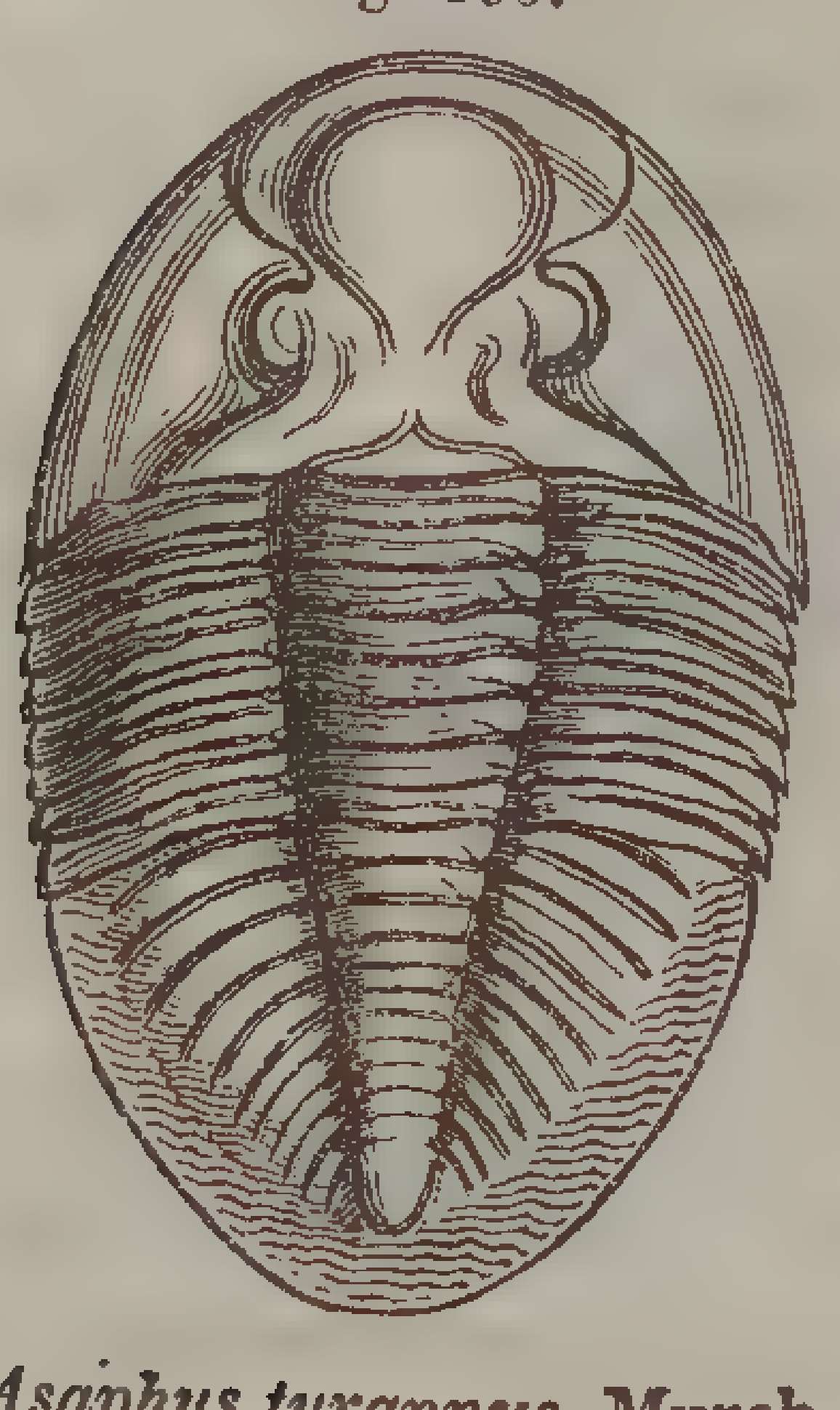
Orthis vespertilio, Sow.
Shropshire; N. & S. Wales.
½ nat. size.

Fig. 594.

Strophomena (*Orthis*) *grandis*, Sowerby.
⅔ nat. size.
Horderly, Shropshire; also Coniston, Lancashire.

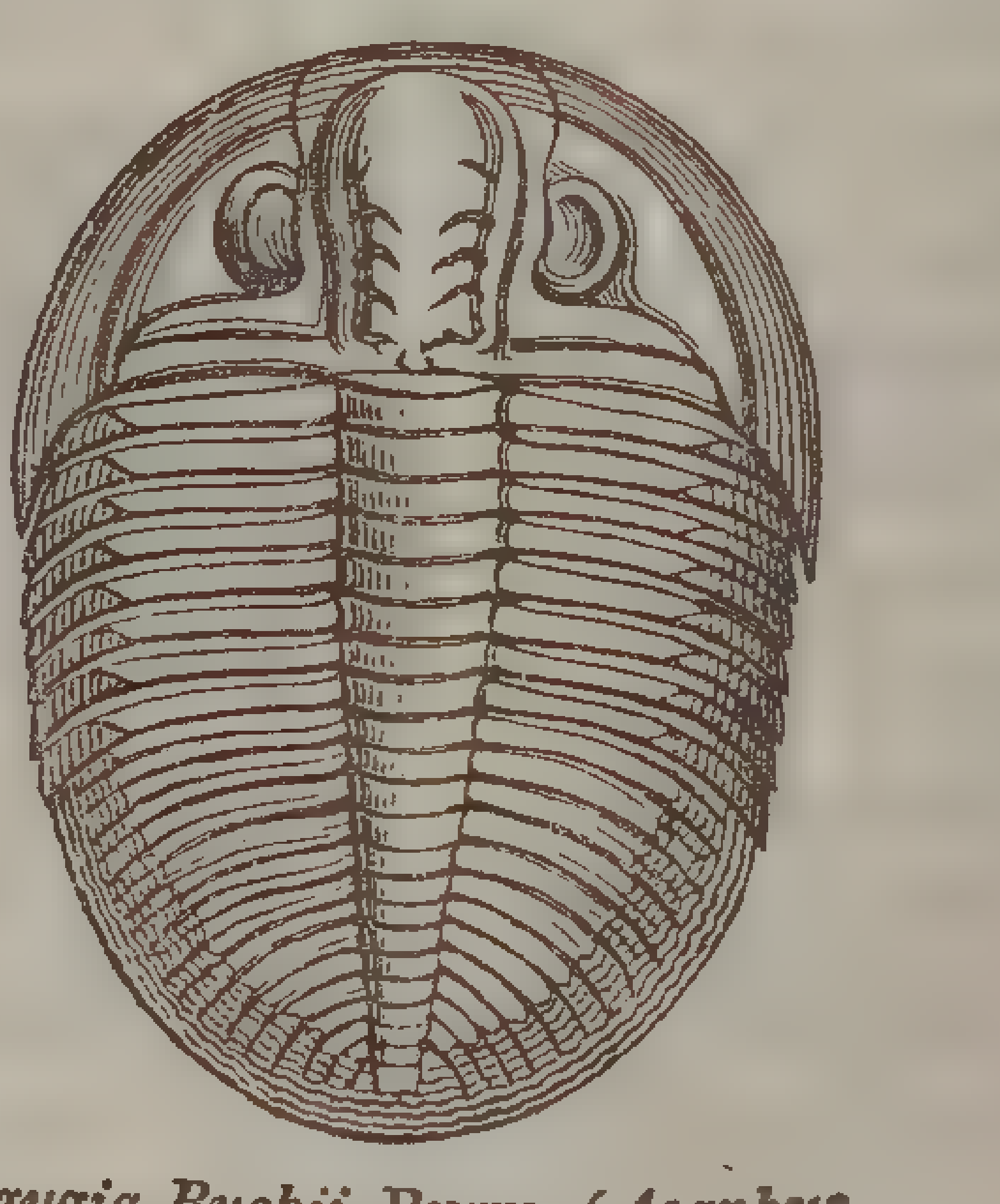
Among the Cephalopoda are *Orthoceratites*, with the siphuncle of large dimensions and placed on one side; also *Lituites* (see fig. 577.), *Bellerophon* (see p. 411.), and some of the floating tribes of mollusca (Pteropods). The Crustaceans were plentifully represented by the Trilobites, which appear to have swarmed in the Silurian seas just as crabs and shrimps do in our own. The genera *Asaphus* (fig. 595.), *Ogygia* (fig. 596.), and *Trinucleus* (figs. 597, 598.) are

Fig. 595.



Asaphus tyrannus, Murch.
Llandeilo; Bishop's Castle, &c.

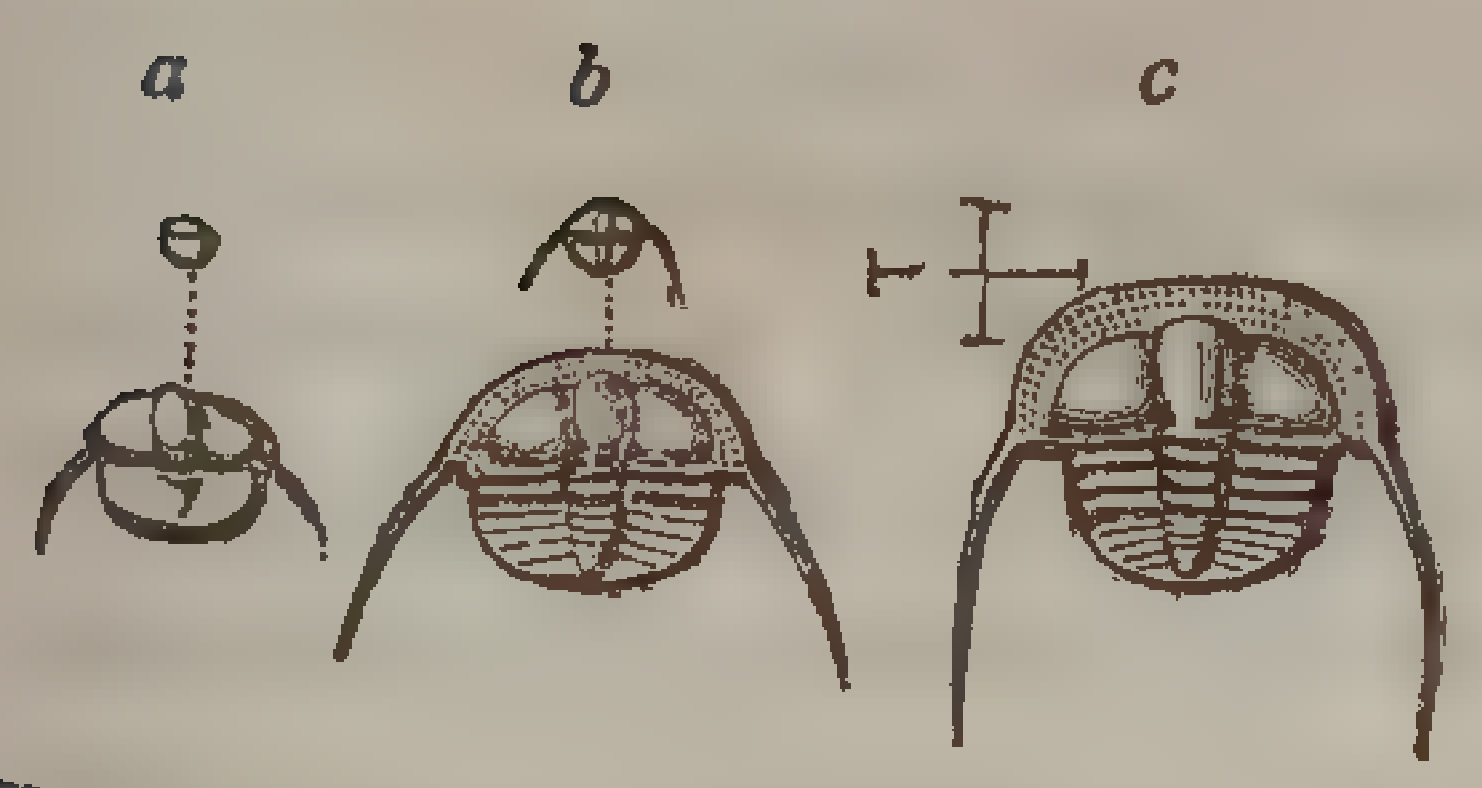
Fig. 596.



Ogygia Buchii, Burm. (*Asaphus Buchii*, Brongn.)
Builth, Radnorshire; Llandeilo, Caermarthenshire.

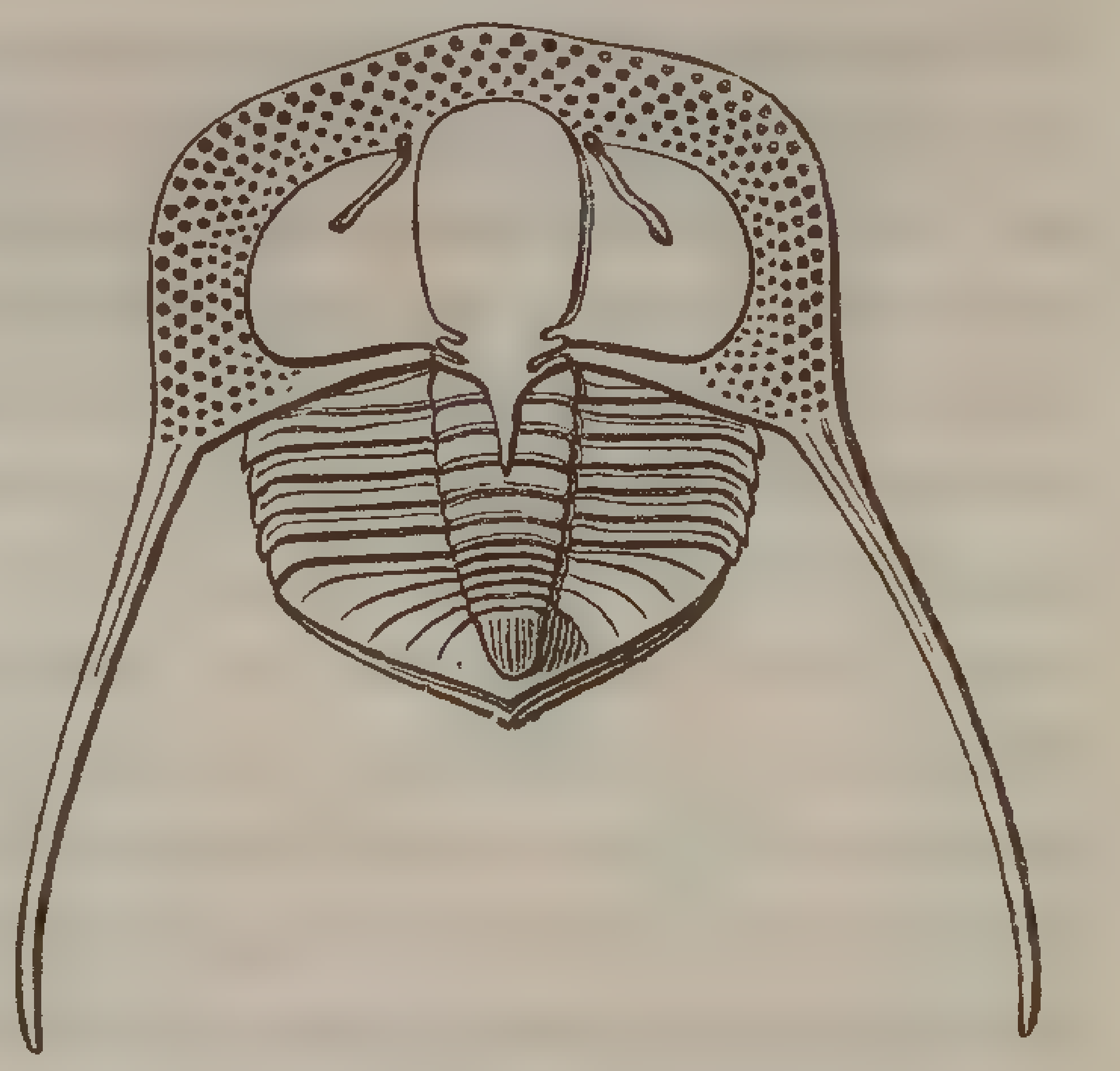
especially characteristic of strata of this age, if not entirely confined to them; but very numerous other genera accompany these. Burmeister, in his work on the organization of trilobites, supposes them to have swum at the surface of the water in the open sea and near coasts, feeding on smaller marine animals, and to have had the power of rolling themselves into a ball as a defence against injury. He was also of opinion that they underwent various transformations analogous to those of living crustaceans. M. Barrande, author of an admirable work on the Silurian rocks of Bohemia, confirms the doctrine of their metamorphosis, having traced more than twenty species through different stages of growth from the young state just after its escape from the egg to the adult form. He has followed some of them from a point in which they show no eyes, no joints to the body, and no distinct tail, up to the complete form with the full number of segments. This change is brought about before the animal has attained a tenth part of its full dimensions, and hence such minute and delicate specimens are rarely met with. Some of his figures of the metamorphoses of the common *Trinucleus* are copied in the annexed wood-cuts (figs. 597, 598.).

Fig. 597.



Young individuals of *Trinucleus concentricus* (*T. ornatus*, Barr.)
- *a*. Youngest state. Natural size and magnified; the body rings not at all developed.
- *b*. A little older. One thorax joint.
- *c*. Still more advanced. Three thorax joints. The fourth, fifth, and sixth segments are successively produced, probably each time the animal moulted its crust.

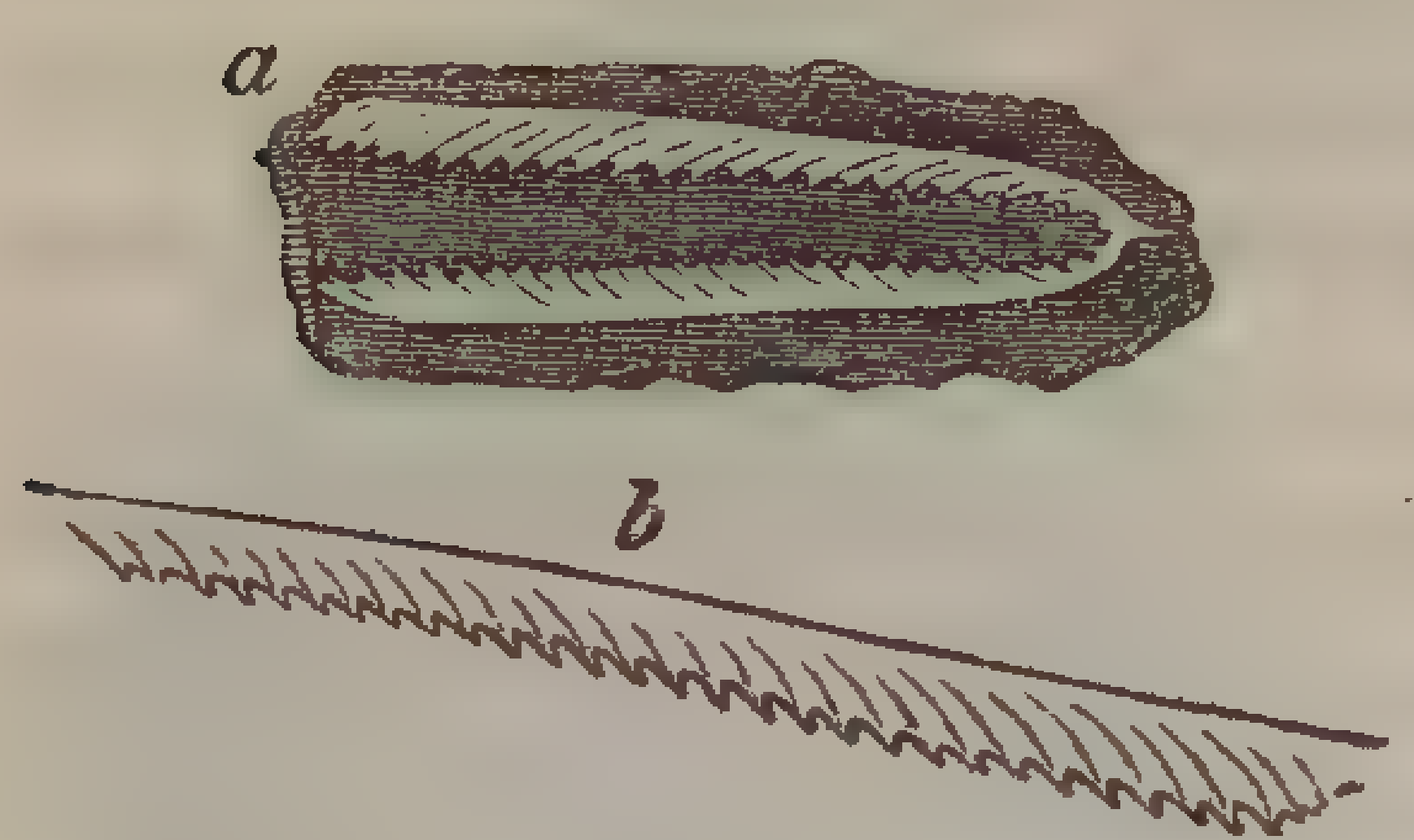
Fig. 598.



Trinucleus concentricus, Eaton.
Syn. *T. caractaci*, Murch.
N. Ireland; Wales; Shropshire; N. America; Bohemia.

A still lower part of the Llandeilo or Bala rocks consists of a black carbonaceous slate of great thickness, frequently containing sulphate of alumina and sometimes, as in Dumfriesshire. beds of anthracite. It has been conjectured that this carbonaceous matter may be due in great measure to large quantities of imbedded animal remains, for the number of Graptolites included in these slates was certainly very great. I collected these same bodies in great numbers in Sweden and Norway in 1835-6, both in the higher and lower graptolitic shales of the Silurian system; and was informed by Dr. Beck of Copenhagen, that they were fossil zoophytes related to the *Vigularia* and *Pennatula*, genera of which the living species now inhabit mud and slimy sediment. The most eminent naturalists still hold to this opinion.

Fig. 599.

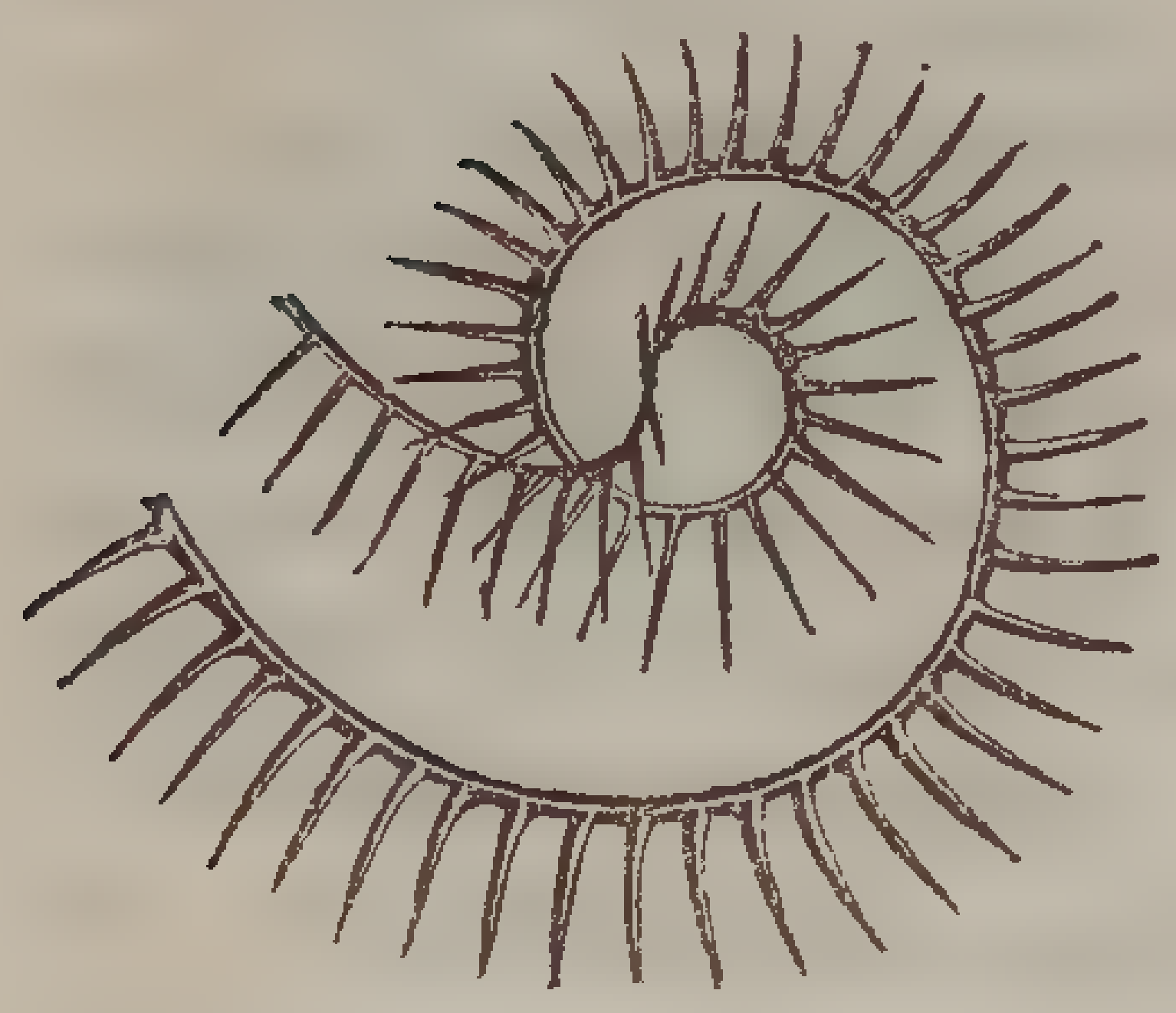


a, b. Didymograpsus (Graptolites) Murchisonii, Beck.
Llandeilo flags. Wales.

Fig. 600.

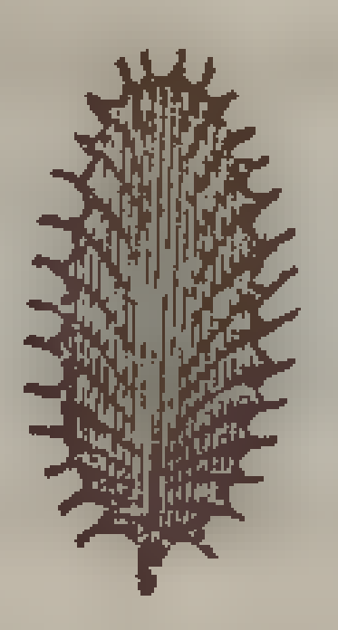
Didymograpsus geminus, Hisinger, sp.
Sweden.

Fig. 601.



Rastrites peregrinus, Barrande.
Scotland ; Bohemia ; Saxony.

Fig. 602.



Diplograpsus folium,
Hisinger.
Scotland ; Sweden.

Fig. 603.

Diplograpsus pristis,
Hisinger. sp.
Shropshire ; Wales ; Sweden,
&c.

Beneath the black slates above described no graptolites appear as yet to have been found, but the characteristic shells and trilobites of the Lower Silurian rocks are still traceable downwards, in North and South Wales, through a vast depth of shaly beds, interstratified with trappean formations, sometimes not less in their aggregate thickness than 11,000 feet. Hence the total thickness of the beds assigned to the Lower Silurian, or the Llandeilo group of Murchison, is not less than 20,000 feet, and the Upper Silurian rocks are above 5000 feet in addition. If these beds were all exclusively of sedimentary origin we might well expect, from the analogy of other parts of the earth's crust, to find that they must be referred paleontologically to more than one era ; in other words, that changes in animal and vegetable life, as great as those which occurred in the course of several such periods as the Devonian, Carboniferous, and Permian, would be found to have taken place while the accumulation of so enormous a pile of rocks was effected. But in volcanic archipelagos, as in the Canaries for example, we see the most active of all known causes, aqueous and igneous, simultaneously at work to produce great results in a comparatively moderate lapse of time. The outpouring of repeated streams of lava,—the showering down upon land and sea of volcanic ashes,—the sweeping seaward of loose sand and cinders, or of rocks ground down to pebbles and sand, by torrents descending steeply inclined channels,—the undermining and eating away of long lines of sea-cliff exposed to the swell of a deep and open ocean,—above all, the injection, both above and below the sea-level, of sheets of melted matter between the lavas previously formed at the surface,—these operations may combine to produce a considerable volume of superimposed matter, without there being time for any extensive change of species.

Nevertheless, there would seem to be a limit to the thickness of stony masses formed even under such favourable circumstances, for the analogy of tertiary volcanic regions lends no countenance to the notion that sedimentary and igneous rocks 25,000, much less 45,000 feet thick, like those of Wales, could originate while one and the same fauna should continue to people the earth. If, then, we allow that 25,000 feet of matter may be ascribed to one system, such as the Silurian, from the top of "the Ludlow" to the base of "the Llandeilo" inclusive, we may be prepared to find in the next series of subjacent rocks, the commencement of another assemblage of species, or even in part of genera, of organic remains. Such appears to be the fact, and I shall therefore conclude with the Llandeilo beds, the original base-line of Sir R. Murchison, my account of the Silurian formations in Great Britain, and proceed to say something of their foreign equivalents, before treating of rocks older than the Silurian.

It would lead me into too long a digression to attempt to follow the Upper, Middle, and Lower Silurian into Scotland, the lake country, Cornwall, and other parts of the British Isles. For an account of these rocks in Ireland, the reader is referred to Col. Portlock's Report on Tyrone, to the writings of Mr. Griffith and Prof. M'Coy, and those of the officers of the Government Survey, as well as to the sketch recently given by Sir R. I. Murchison.

When we turn to the Continent of Europe, we discover the same ancient series occupying a wide area, but in no region as yet has it been observed to attain great thickness. Thus, in Norway and Sweden, the total thickness of strata of Silurian age is scarcely equal to 1000 feet*, although the representatives both of the Upper and Lower Silurian of England are not wanting there, and even some beds of schist have been comprehended which, as we shall hereafter see, lie below the Llandeilo group. In Russia the Silurian strata, so far as they are yet known, seem to be even of smaller vertical dimensions than in Scandinavia, and they appear to consist chiefly of Middle and Lower Silurian, or of a limestone containing *Pentamerus oblongus*, below which are strata with fossils corresponding to those of the Llandeilo beds of England. The lowest rock with organic remains yet discovered is "the Ungulite or Obolus grit" of St. Petersburg, probably coeval with the Llandeilo, and not exhibiting any of those peculiar forms which distinguish "the Lingula flags" of Wales, or the Bohemian "primordial fauna" of Barrande.

The shales and grits near St. Petersburg, above alluded to, contain green grains in their sandy layers, and are in a singularly unaltered state, taking into account their high antiquity. The prevailing brachiopods consist of the *Obolus* or Ungulite of Pander, and a *Siphonotreta* (see figs. 604, 605.). As bearing on the antiquity of this formation, it is interesting to notice that both genera have recently been found in our own Dudley limestone.

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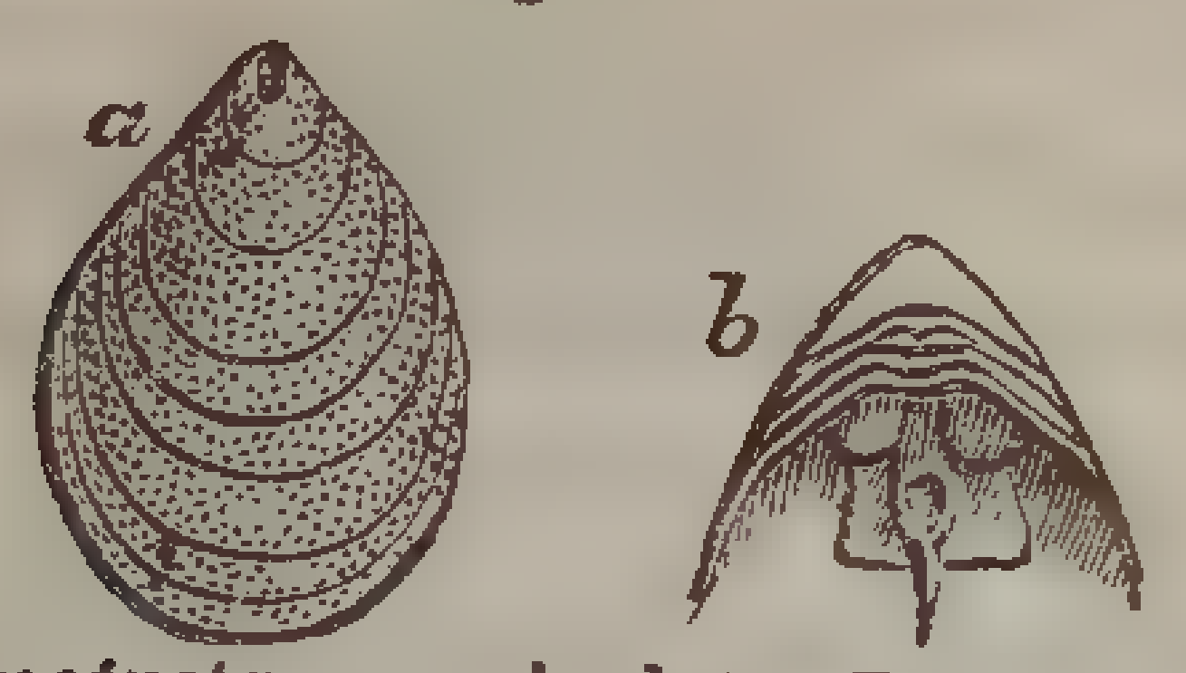
* Murchison's Siluria, p. 321.

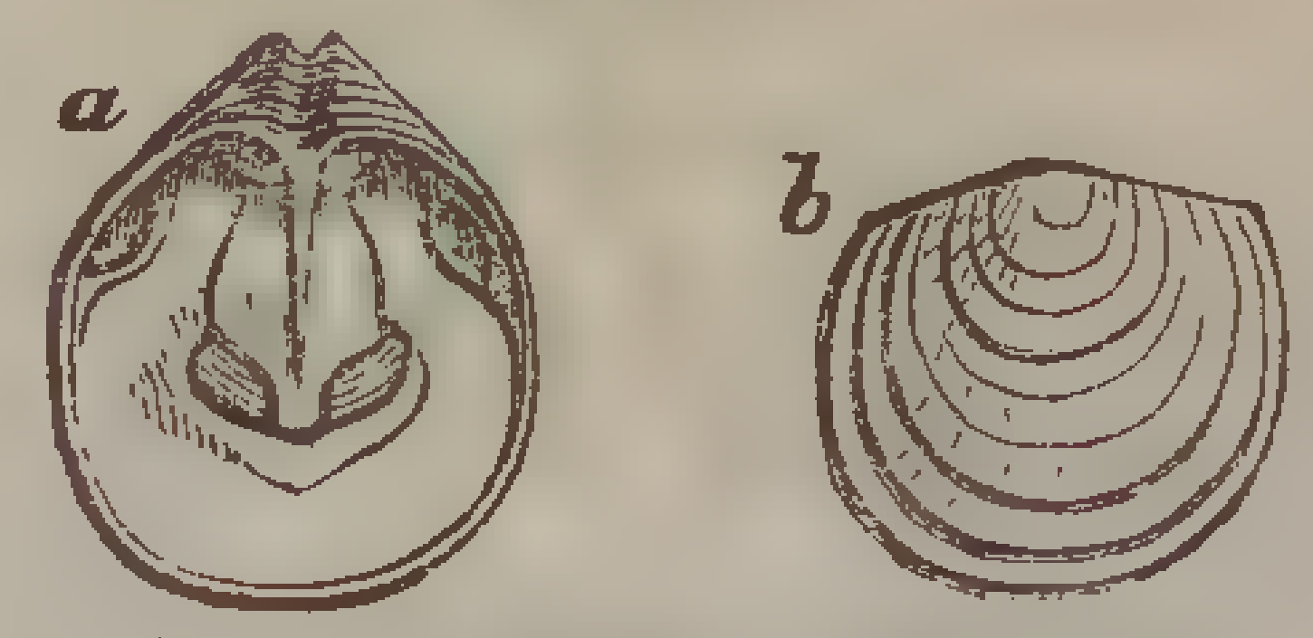
Shells of the lowest known Fossiliferous Beds in Russia.

Fig. 604.



Siphonotreta unguiculata, Eichwald.
From the Lowest Silurian sandstone, "Obolus grits," of Petersburg.
a. outside of perforated valve.
b. interior of same, showing the termination of the foramen within.

Fig. 605.



Obolus Apollinis, Eichwald.
From the same locality.
a. interior of the larger or ventral valve.
b. exterior of the upper (dorsal) valve.
(Davidson.)

Among the green grains of the sandy strata above mentioned, Professor Ehrenberg has recently (1854) announced his discovery of remains of foraminifera. These are casts of the cells; and amongst five or six forms three are considered by him as referable to existing genera (e. g., *Textularia*, *Rotalia*, and *Guttulina*).

SILURIAN STRATA OF THE UNITED STATES.

The position of some of these strata, where they are bent and highly inclined in the Appalachian chain, or where they are nearly horizontal to the west of that chain, is shown in the section, fig. 505. p. 392. But these formations can be studied still more advantageously north of the same line of section, in the States of New York, Ohio, and other regions north and south of the great Canadian lakes. Here they are found, as in Russia, nearly in horizontal position, and are more rich in well-preserved fossils than in almost any spot in Europe. In the State of New York, where the succession of the beds and their fossils have been most carefully worked out by the Government Surveyors, the subdivisions given in the first column of the annexed list have been adopted.

Subdivisions of the Silurian Strata of New York. (Strata below the Oriskany Sandstone, see Table, p. 430.)

New York Names.	British Equivalents.
1. Upper Pentamerus Limestone	Upper Silurian (or Ludlow and Wenlock formations).
2. Encrinal Limestone	
3. Delthyris Shaly Limestone	
4. Pentamerus Limestone	
5. Tentaculite Limestone	
6. Onondaga Salt-group	
7. Niagara Group	
8. Clinton Group	Middle Silurian (or Caradoc Sandstone).
9. Medina Sandstone	
10. Oneida Conglomerate	
11. Grey Sandstone	
12. Hudson River Group.	Lower Silurian (or Llandeilo beds).
13. Utica Slate	
14. Trenton Limestone	
15. Black-River Limestone	
16. Bird's-Eye Limestone	
17. Chazy Limestone	
18. Calciferous Sandstone	
19. Potsdam Sandstone	Cambrian ? (or Lingula flags and beds, older than "the Llandeilo").

In the second column of the same table I have added the supposed British equivalents. All paleontologists, European and American, such as MM. de Verneuil, D. Sharpe, Prof. Hall, and others, who have entered upon this comparison, admit that there is a marked general correspondence in the succession of fossil forms, and even species, as we trace the organic remains downwards from the highest to the lowest beds; but it is impossible to parallel each minor subdivision. In regard to the three following points there is little difference of opinion.

1st. That the Niagara Limestone, No. 7., over which the river of that name is precipitated at the great cataract, together with its underlying shales, corresponds to the Wenlock limestone and shale of England. Among the species common to this formation in America and Europe are *Calymene Blumenbachii, Homalonotus delphinocephalus* (fig. 587.), with several other trilobites; *Rhynchonella Wilsoni,* and *R. cuneata; Orthis elegantula, Pentamerus galeatus,* with many more brachiopods; *Orthoceras annulatum,* among the cephalopodous shells; and *Favosites gothlandica,* with other large corals.

2nd. That the Clinton Group, No. 8., containing *Pentamerus oblongus* and *P. lævis,* and related more nearly by its fossil species with the beds above than with those below, is the equivalent of the Middle Silurian as above defined, p. 441.

3rd. That the Hudson River Group, No. 12., and the Trenton Limestone, No. 14., agree paleontologically with the Llandeilo flags, containing in common with them several species of trilobites, such as *Asaphus (Isotelus) gigas, Trinucleus concentricus* (fig. 598. p. 445.); and various shells, such as *Orthis striatula, Orthis biforata* (or *O. lynx*), *O. porcata* (*O. occidentalis* of Hall), *Bellerophon bilobatus,* &c.*

Mr. D. Sharpe, in his report on the mollusca collected by me from these strata in North America †, has concluded that the number of species common to the Silurian rocks on both sides of the Atlantic is between 30 and 40 per cent.; a result which, although no doubt liable to future modification, when a larger comparison shall have been made, proves, nevertheless, that many of the species had a wide geographical range. It seems that comparatively few of the gasteropods and lamellibranchiate bivalves of North America can be identified specifically with European fossils, while no less than two-fifths of the brachiopoda, of which my collection chiefly consisted, are the same. In explanation of these facts, it is suggested that most of the recent brachiopoda (especially the orthidiform ones) are inhabitants of deep water, and that they may have had a wider geographical range than shells living near shore. The predominance of bivalve mollusca of this peculiar class has caused the Silurian period to be sometimes styled "the age of brachiopods."

The calcareous beds, Nos. 15, 16, 17, and 18., below the Trenton Limestone have been considered by M. de Verneuil as Lower Silurian, because they contain certain species, such as *Asaphus (Isotelus) gigas, Illænus crassicauda,* and *Orthoceras bilineatum,* in common with the overlying Trenton Limestone.‡ But, according to

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* See Murchison's Siluria, p. 414.

† Quart. Geol. Journ., vol. iv.

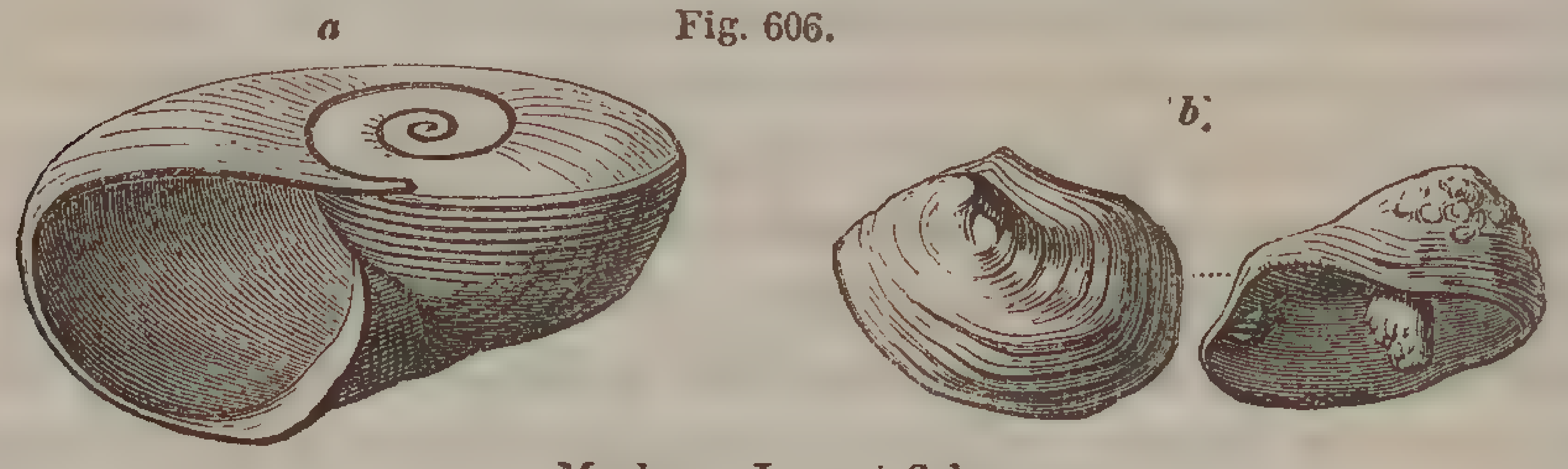
‡ Soc. Géol. France, Bulletin, vol. iv. p. 651. 1847.

Prof. Hall, the *Illænus* was erroneously identified, an error to which he confesses that he himself contributed; and on the whole these lower beds contain, he thinks, a very distinct set of species, only three or four of them out of eighty-three passing upwards into the incumbent formations.*

Be this as it may, the Black River Limestone, No. 15., contains certain forms of *Orthoceras* of enormous size (some of them 8 or 9 feet long!), of the subgenera *Ormoceras* and *Endoceras*, seeming to represent the Lower Silurian or Orthoceras limestone of Sweden. Moreover, the general facies of the fauna of all these beds is essentially similar. Another ground for extending our comparison of the Llandeilo beds of Europe as far down as the calciferous sandstone is derived from the researches of Mr. Logan in Canada, and the study by Mr. Salter of the fossils collected by the Canadian Surveyor near the S. E. end of the Ottawa River, where one mass of limestone incloses species common to all the beds from the Calciferous Sandstone (No. 18.) up to the Trenton Limestone (No. 14.). In this rock, the *Asaphus gigas* and other well-known Trenton species are blended with the *Maclurea* (a left-handed *Euomphalus*, fig. 606.), a genus characteristic of the Chazy Limestone, or No. 17; and *Murchisonia gracilis* (fig. 607.) is another Trenton Limestone species found in the same Silurian limestone of Canada †; while one of the most common shells in it is the *Raphistoma?* (*Euomphalus*) *uniangulatum*, Hall, a species characteristic in New York of the Calciferous Sandstone itself.

Fossils from Allumette Rapids, River Ottawa, Canada.

Fig. 606.



Maclurea Logani, Salter.
a. view of the shell. *b.* its curious operculum.

Fig. 607.

Murchisonia gracilis, Hall.
A fossil characteristic of the Trenton Limestone. The genus is common in Lower Silurian rocks.

In Canada, as in the State of New York, the Potsdam Sandstone underlies the above-mentioned calcareous rocks, but contains a different suite of fossils, as will be hereafter explained. In parts of the globe still more remote from Europe the Silurian strata have also been recognized, as in South America, Australia, and recently by Captain Strachey in India. In all these regions the facies of the fauna, or the types of organic life, enable us to recognize the contemporaneous origin of the rocks; but the fossil species are distinct, showing that the old notion of a universal diffusion throughout the "primæval seas" of one uniform specific fauna was

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* Hall; Forster and Whitney's Report on Lake Superior, Pt. II. 1851.

† Logan, Report, Brit. Assoc. Ipswich, pp. 59. 63.

quite unfounded, geographical provinces having evidently existed in the oldest as in the most modern times.*

Whether the Silurian rocks are of deep-water origin. — The grounds relied upon by Professor E. Forbes for inferring that the larger part of the Silurian Fauna is indicative of a sea more than 70 fathoms deep, are the following: first, the small size of the greater number of conchifera; secondly, the paucity of pectinibranchiata (or spiral univalves); thirdly, the great number of floaters, such as *Bellerophon, Orthoceras,* &c.; fourthly, the abundance of orthidiform brachiopoda; fifthly, the absence or great rarity of fossil fish.

It is doubtless true that some living *Terebratulæ*, on the coast of Australia, inhabit shallow water; but all the known species, allied in form to the extinct *Orthis*, inhabit the depths of the sea. It should also be remarked that Mr. Forbes, in advocating these views, was well aware of the existence of shores, bounding the Silurian sea in Shropshire, and of the occurrence of littoral species of this early date in the northern hemisphere. Such facts are not inconsistent with his theory; for he has shown, in another work, how, on the coast of Lycia, deep sea strata are at present forming in the Mediterranean, in the vicinity of high and steep land.

Had we discovered the ancient delta of some large Silurian river, we should doubtless have known more of the shallow-water, brackish-water, and fluviatile animals, and of the terrestrial flora of the period under consideration. To assume that there were no such deltas in the Silurian world, would be almost as gratuitous an hypothesis, as for the inhabitants of the coral islands of the Pacific to indulge in a similar generalization respecting the actual condition of the globe.

CAMBRIAN GROUP.

Upper Cambrian. — We have next to consider the fossiliferous strata that occupy a lower position than the "Llandeilo beds," which last form, as we have seen, the Lower division of the great Silurian series, as originally defined by Sir R. Murchison. In the Appendix to his important work before cited†, Sir Roderick has given, on the authority of Mr. Salter, a list of no less than 96 species of fossils (of which specimens have been examined either by himself or Prof. McCoy), all common to the Upper and Lower Silurian strata, or, in other words, which, being found either in the Ludlow or Wenlock beds, are also met with in the Llandeilo formation. The range upwards of so many species from the inferior to the superior group shows that, independently of the link supplied by the Caradoc or Middle Silurian, there is such a connection between the two principal divisions, as makes it natural to assign the whole to one great period. To attempt, therefore, to give a new name to the Llandeilo beds, or to call them *Cambrian*, as has been recently proposed by some geologists, would

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* E. Forbes, Anniv. Address, 1854. Quart. Journ. Geol. Soc., vol. x. p. 38.

† Siluria, p. 485.

be to act in violation of the ordinary rules of classification, and would create much confusion, by disturbing a nomenclature long received and originally established on well-defined paleontological data.

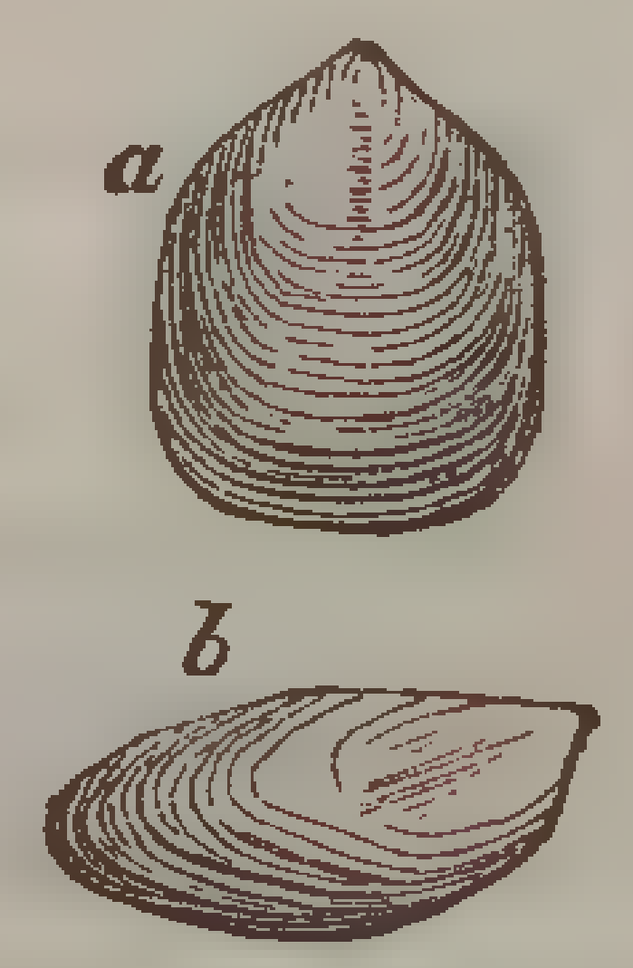
In Shropshire, the classical region, where the type of the Silurian group was first made out by Murchison, the formations subjacent to the Llandeilo consisted of quartzose rocks, sterile of fossils, or yielding little more than some obscure fucoids. In North Wales, Professor Sedgwick found below the Bala Limestone, long since recognized as the equivalent of the Llandeilo flags, a vast thickness of sedimentary and volcanic rocks, the lithological characters and physical features of which he studied assiduously for years, dividing them into well-marked formations, to which he affixed names. Collectively they constituted the chief part of the rocks called by him "Cambrian." They were devoid of limestone; but in a group of micaceous sandstones Mr. E. Davis discovered in 1846 the *Lingula* named after him, and from which the name of "Lingula flags" has since been derived. In these flags, about 1500 or 2000 feet in thickness, several other fossils were afterwards found, of different species from those in the Llandeilo beds. Amongst them, trilobites, *Agnostus* and *Conocephalus* (for genus, see fig. 614.), and some rare Brachiopoda and Bryozoa, still unpublished by our Government surveyors, have been detected, and in the inferior black slates of North Wales a trilobite called *Paradoxides* (for genus, see fig. 613.), a form still more characteristic of this era, together with another of the genus *Olenus* (fig. 610.), and a phyllopod crustacean (fig. 608.).

Fossils of the "Lingula Flags," or lowest Fossiliferous Rocks of Britain.

Fig. 608.

Hymenocaris vermicauda, Salter.
A Phyllopod Crustacean.
½ nat. size.

Fig. 609.



Lingula Davisii, M'Coy.
a. ½ natural size.
b. distorted by cleavage.

Fig. 610.

Olenus micrurus, Salter.
½ nat. size.

"Lingula Flags" of Dolgelly, and Ffestiniog; N. Wales.

I have before observed, that between the Bala Limestone and the Lingula Flags there is a thickness of 11,000 feet of strata, in which *Graptolites* and certain species of *Asaphus*, *Calymene*, and *Ogygia* occur. These may be referred at present to the Silurian series, but the exact limits between them and the Lingula Flags cannot yet be assigned.

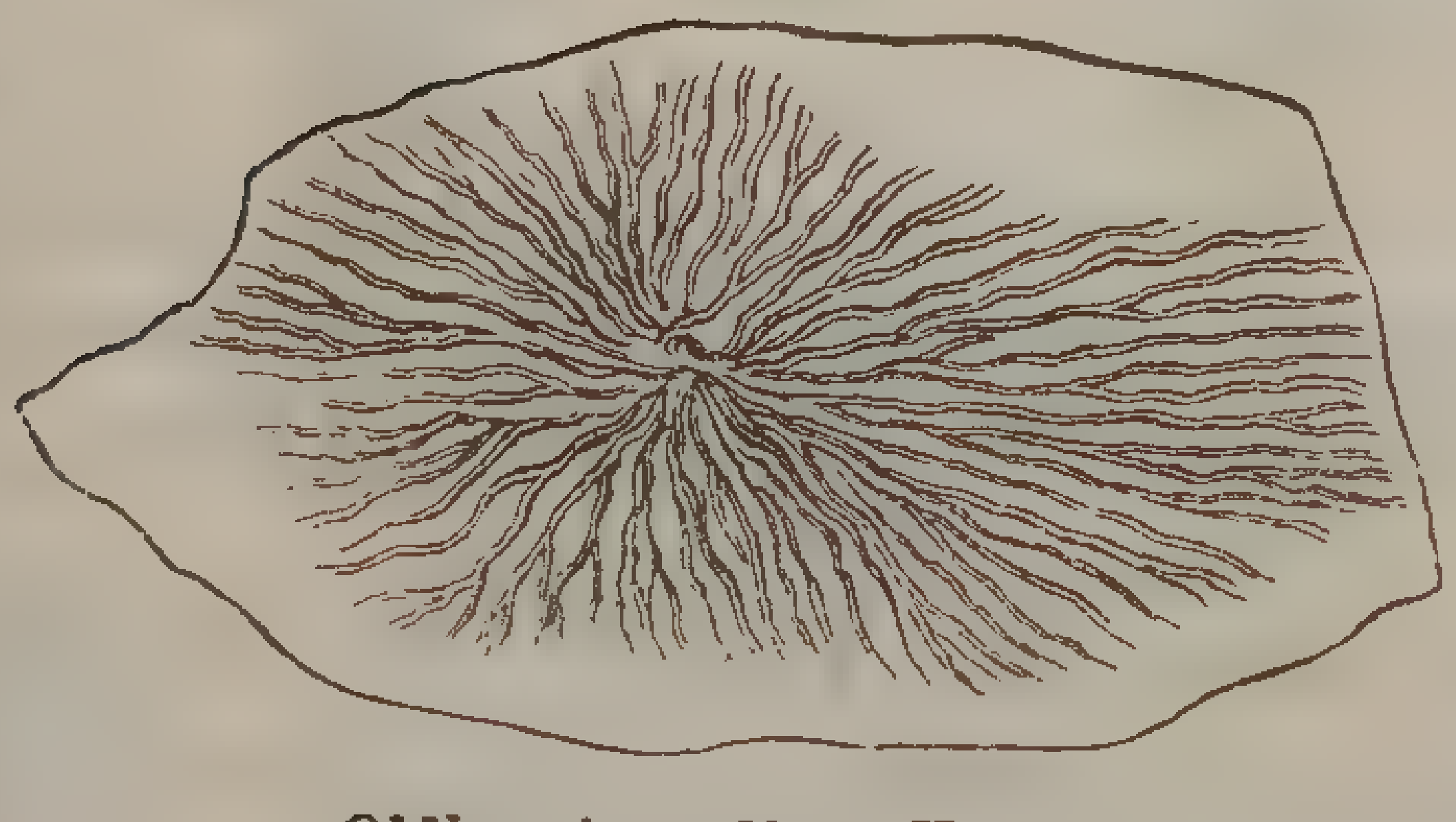
We might have anticipated, as already remarked, p. 446., that, whenever a fossil Fauna was discovered in the Cambrian strata, it would be found to consist of distinct species, and even, to a large extent, of distinct genera; for, although geological periods are of very unequal value in regard to the lapse of time (see p. 104.), and our lines of separation may often be somewhat arbitrary, yet in no part of the world have we hitherto examined a succession of rocks having so great a thickness as 45,000 feet, even where they are made up in part of volcanic materials, which have been referred to one period as being characterized by one and the same fauna.

The first formation mentioned by Prof. Sedgwick, beneath the Bala Limestone (and its associated beds of sandstone) in N. Wales, are certain beds, 7000 feet thick, called the Arenig slates and porphyry. Under them he finds the Tremadoc Slates, 1000 feet thick, and next the Lingula Flags, already described, 1500 feet or more, which, in accordance with views first put forward by Mr. Salter, I have referred provisionally to an Upper Cambrian group.

Lower Cambrian. — To the Lingula Flags last enumerated, another series, called by Prof. Sedgwick the Bangor Group, succeeds in the descending order, comprising, 1st, the Harlech Grits, 500 feet thick, and next the Llanberis Slates, 1000 feet. These formations have as yet proved barren of organic remains in N. Wales; but in Ireland, immediately opposite Anglesea and Caernarvon, rocks of the same mineral character as the Bangor Group, and occupying precisely the same place in the geological series, have afforded two species of zoophytes, to which Professor Forbes has given the name of *Oldhamia* (figs. 611 and 612.). The position of these rocks has been decided by the Government Surveyors, and confirmed by Sir R. Murchison, so that here we behold the relics of the most ancient organic bodies yet known. We are of course unable at present to determine whether they belong to the same fauna as the fossils of the "Lingula Flags," or to an older one. The beds containing them may provisionally be called Lower Cambrian, for it will always happen that our inquiries will terminate downwards in rocks affording very imperfect materials for classification. This will continue to be the case, however many steps we may make in future in penetrating into the remoter annals of the past.

The most Ancient Fossils yet known (1854).

Fig. 611.



Oldhamia radiata, Forbes.
Wicklow, Ireland.

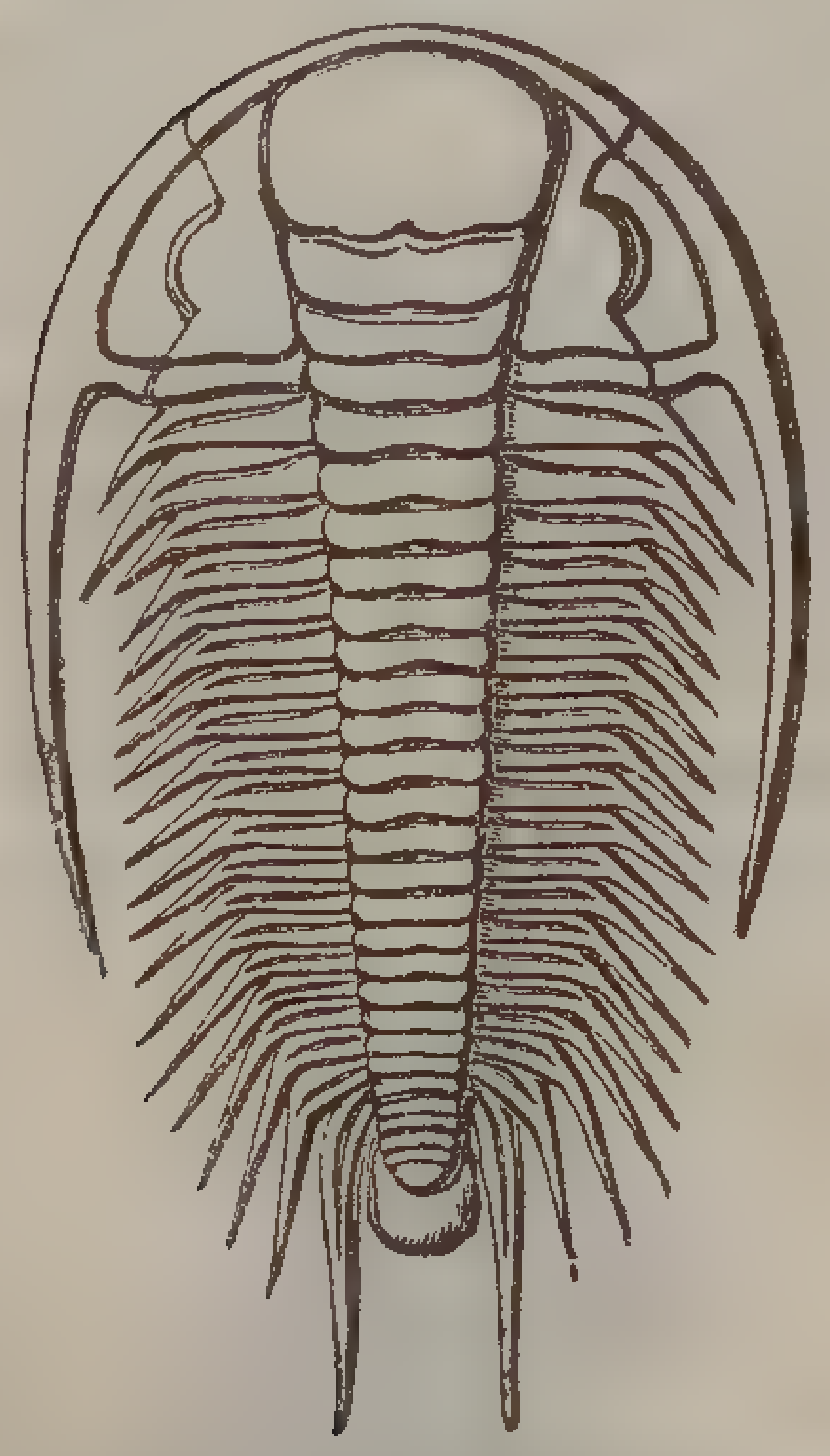
Fig. 612.

Oldhamia antiqua, Forbes.
Wicklow, Ireland.

Bohemia.—M. Barrande, in his admirable monograph on the Paleozoic rocks of Bohemia, has laid much stress on the distinctness and isolation of what he calls the "Protozoic schists," which attain a thickness of 1200 feet, and lie at the base of the whole Silurian group, as defined by him. These schists have no limestone associated with them, and are regarded by M. Barrande as contemporaneous with the "Lingula Flags" of N. Wales. So far as he has yet carried his researches, this "primordial fauna," as he designates it, has yielded scarcely any other fossils than Trilobites, the other animal remains consisting of a Pteropod, some Cystideæ, and an *Orthis*, all of new and peculiar species. Of the Trilobites, even the genera, with the exception of one (*Agnostus*, figs. 615 and 616.), are peculiar. These genera are *Paradoxides* (see fig. 613.), of which there are no less than twelve species, *Conocephalus* (fig. 614.), *Ellipsocephalus*, *Sao* (fig. 617.), *Arionellus*, and *Hydrocephalus*. They have all a facies of their own, dependent on the multiplication of their thoracic segments, and the diminution of their caudal shield or pygidium.

Fossils of the lowest Fossiliferous Beds in Bohemia, or "Primordial Zone" of Barrande.

Fig. 613.

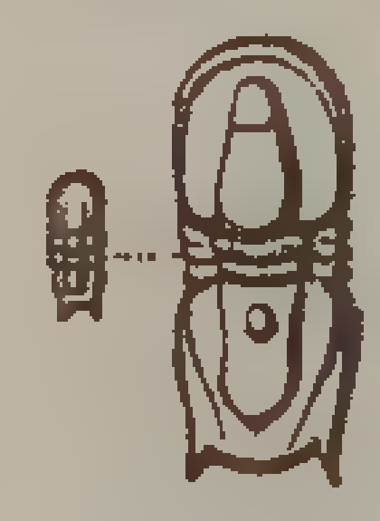


Paradoxides Bohemicus, Barr.
About one third natural size.
"Lowest Silurian beds" of Ginetz, Bohemia.
(Etage C. of Barrande.)

Fig. 614.

Conocephalus striatus, Emmrich.
½ nat. size.
Ginetz and Skrey.

Fig. 615.

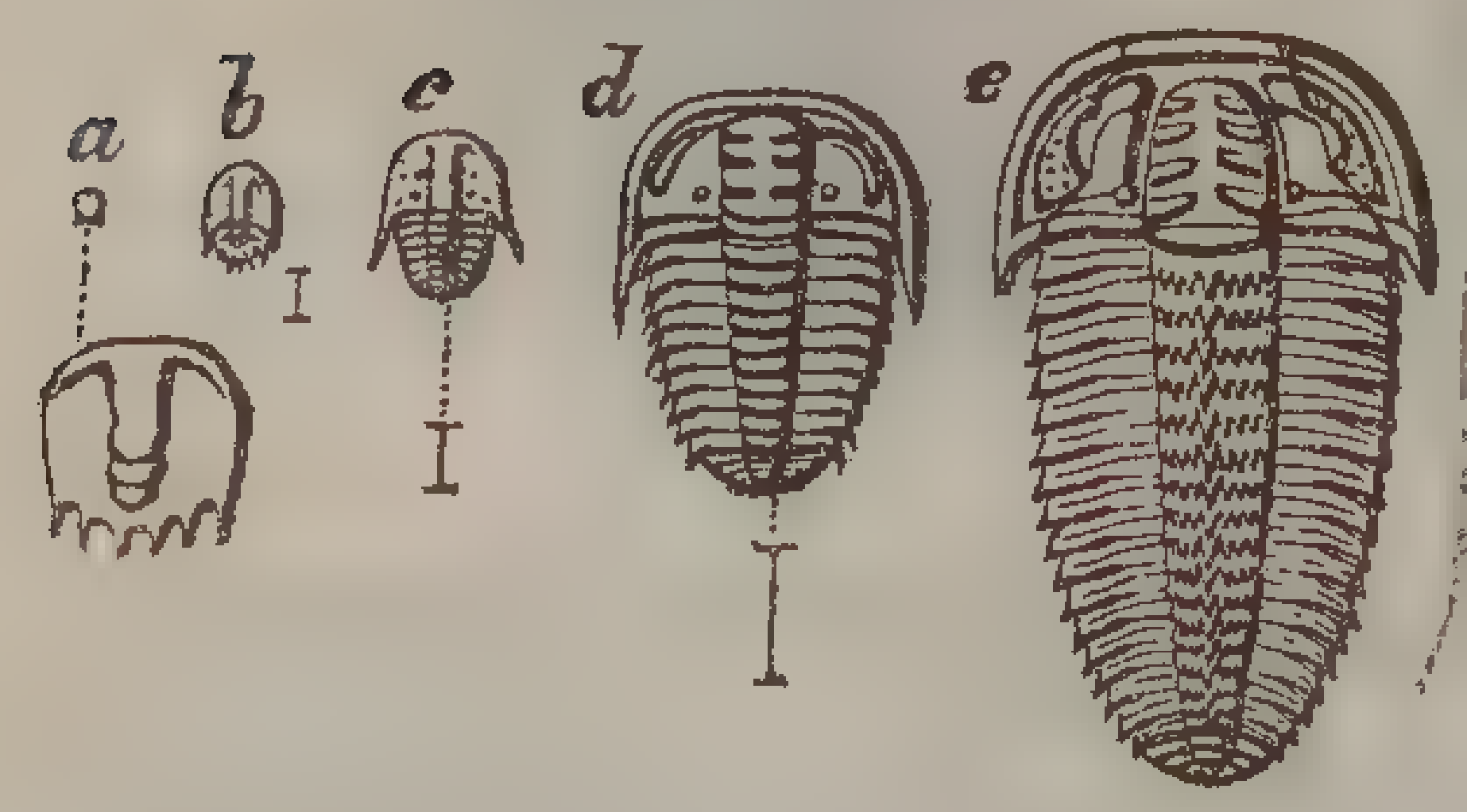


Agnostus integer, Beyrich.
Nat. size and magnified.

Fig. 616.

Agnostus Rex, Barr.
Nat. size, Skrey.

Fig. 617.



Sao hirsuta, Barrande, in its various stages of growth. Skrey.

The small lines beneath indicate the true size. In the youngest state, *a*, no segments are visible; as the metamorphosis progresses, *b*, *c*, the body segments begin to be developed; in the stage *d* the eyes are introduced, but the facial sutures are not completed; at *e* the full-grown animal, half its true size, is shown.

All the Bohemian species differ as yet from any found in England, which may be owing chiefly to the very small number as yet known in Great Britain; or it may be due entirely to the influence of geographical causes It seems nevertheless to confirm the view here taken, of the "primordial zone" being characterized by fossils distinguishable from the Llandeilo, or Lower Silurian group; because the other and higher Silurian formations of Barrande have each of them many species in common with the successive subdivisions of the British series.

One of the so-called "primordial" Trilobites of the genus *Sao*, a form not found as yet elsewhere in the world, has afforded M. Barrande a fine illustration of the metamorphosis of these creatures; for he has traced them through no less than twenty stages of their development. A few of these changes have been selected for representation in the accompanying figures, that the reader may learn the gradual manner in which different segments of the body and the eyes make their appearance. When we reflect on the altered and crystalline condition usually belonging to rocks of this age, and how devoid of life they are for the most part in North Wales, Ireland, and Shropshire, the information respecting such minute details of the Natural History of these crustaceans, as is supplied by the Bohemian strata, may well excite our astonishment, and may reasonably lead us to indulge a hope that geologists may one day gain an insight into the condition of the planet and its inhabitants at eras long antecedent to the Cambrian; for those parts of the globe which have been subjected to a scrutiny as rigorous as North Wales and Bohemia are insignificant spots, and we are every day discovering new areas, especially in the United States and Canada, where beds as old as the "primordial schists," or older, may be studied.

Sweden and Norway.—The Lingula Flags of North Wales, and the "primordial schists" of Bohemia, are represented in Sweden by strata, the fossils of which have been described by an able naturalist, M. Angelin, in his "Palæontologica Suecica (1852-4)." The "alum schists," as they are called in Sweden, resting on a fucoid-sandstone, contain trilobites belonging to the genera *Paradoxides*, *Olenus*, *Agnostus*, and others, some of which present rudimentary forms, like the genus last mentioned, without eyes, and with the body segments scarcely developed, and others again have the number of segments excessively multiplied, as in *Paradoxides*. These peculiarities agree with the characters of the crustaceans met with in the Upper Cambrian strata, before mentioned.

United States and Canada.—In the table, at p. 448., I have already pointed out the relative position of the Potsdam Sandstone, which has long been known as the lowest fossiliferous formation in the United States and Canada. I have seen it on the banks of the St. Lawrence in Canada, and on the borders of Lake Champlain, where, as at Keesville, it is a white quartzose fine-grained grit, almost passing into quartzite. It is divided into horizontal ripple-marked beds, very like those of the Lingula flags of Britain, and replete with a small round-shaped *Lingula* in such numbers as to divide the rock into parallel planes, in the same manner as do the scales of mica in some micaceous sandstones. This formation, as we learn from Mr. Logan, is 700 feet thick in Canada; the lower portion consisting of a conglomerate with quartz pebbles; the upper part of sandstone containing fucoids, and perforated by small vertical holes, which are very characteristic of the rock, and appear to have been made by annelids (*Scolithus linearis*).

On the banks of the St. Lawrence, near Beauharnois and elsewhere, many fossil footprints have been observed on the surface of its rippled layers. These impressions were first noticed by Mr. Abraham, of Montreal, in 1847, and were supposed to be tracks of a tortoise; but Mr. Logan has since brought some of the slabs to London, together with numerous casts of other slabs, enabling Professor Owen to correct the idea first entertained, and to decide that they were not due to a chelonian, nor, as he imagines, to any vertebrate creature. The Hunterian Professor inclines to the belief that they are the trails of more than one species of articulate animal, probably allied to the King Crab, or *Limulus.* Between the two rows of foot-tracks runs an impressed median line or channel, supposed by the Professor to have been made by a caudal appendage rather than by a prominent part of the trunk. Some individuals appear to have had three, and others five pairs, of limbs used for locomotion. The width of the tracks between the outermost impressions varies from 3½ to 5½ inches, which would imply a creature of much larger dimensions than any organic body yet obtained from strata of such antiquity. Their size alone is therefore important, as warning us of the danger of drawing any inference, from mere negative evidence, as to the extreme poverty of the fauna of the earlier seas.

Mr. Logan informs us*, that the Lower Silurian strata and the Potsdam Sandstone in Canada rest unconformably on a still older series of aqueous rocks, which, as he says, may be Cambrian (Lower Cambrian, or, perhaps, still older?), and which include conglomerates and beds of limestone. In both of these, nodules of phosphate of lime are frequently observed. That these contorted rocks are of aqueous origin, he infers from the presence of quartz pebbles in the conglomerates. Together with the associated igneous masses, this ancient series attains a thickness of at least 10,000 feet, in the Lake Huron district, and includes the copper-bearing rocks of that part of Canada. Below these again lies gneiss, with interstratified marble, in which crystals of phosphate of lime both large and small are not uncommon. This phosphate, as Mr. Logan suggests, may have "a possible connection with life in those ancient rocks."

In the frontispiece to this volume, and in fig. 83. p. 59., the reader may refer to a section on the coast of Scotland where the Devonian strata lie unconformably on the highly inclined Silurian schists, and I have cited the eloquent reflections of Playfair when he looked, with his teacher Hutton, "so far into the abyss of time." But in the lake district of N. America, the Potsdam Sandstone, forming the upper or horizontal series, is older than even the inclined strata of St. Abb's Head in Scotland. In Canada again, we behold the monuments of still another period in the remote distance, attesting, as Playfair exclaimed, "how much farther the reason may go than the imagination can venture to follow."

Valley of the Upper Mississippi.—Mr. Dale Owen has recently published a graphic sketch, in his survey of Wisconsin (1852), of the lowest sedimentary rocks near the head-waters of the Mississippi,

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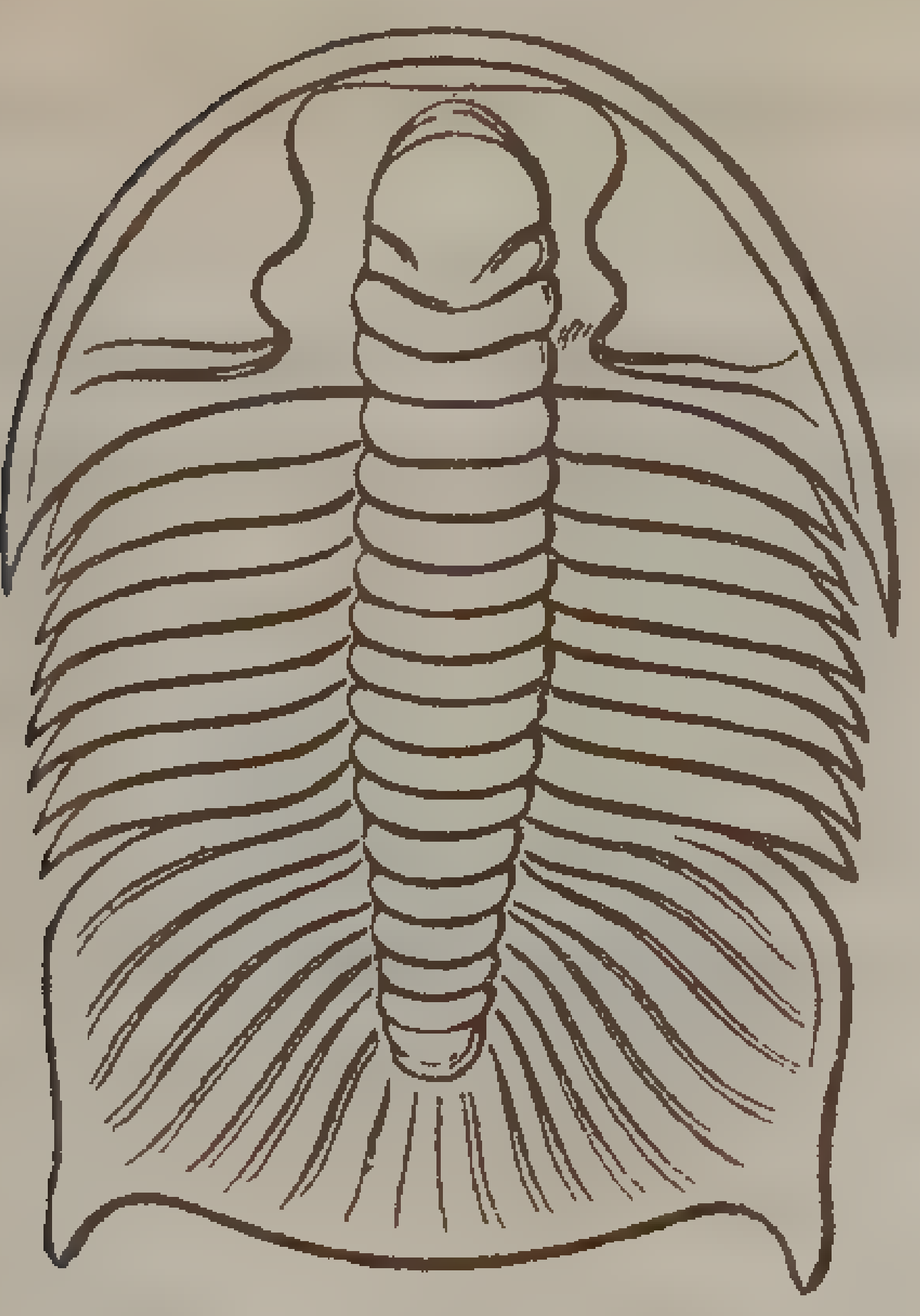
* Quart. Geol. Journ., vol. viii. p. 210.

lying at the base of the whole Silurian series. They are many hundred feet thick, and for the most part similar in character to the Potsdam Sandstone above described, but including in their upper portions intercalated bands of magnesian limestone, and in their lower some argillaceous beds. Among the shells of these strata are species of *Lingula* and *Orthis*, and several trilobites of the new genus *Dikelocephalus* (fig. 618.). These rocks, occurring in Iowa, Wisconsin, and Minnesota, seem destined hereafter to throw great light on the state of organic life in the Cambrian period. Six beds containing trilobites, separated by strata from 10 to 150 feet thick, are already enumerated.

Fig. 618.



Dikelocephalus Minnesotensis, Dale Owen. $\frac{1}{3}$ diameter.
A large crustacean of the Olenoid group. Potsdam Sandstone. Falls of St. Croix, on the upper Mississippi.

Relation of Silurian and Cambrian Faunas. — That there is a considerable connection between the Cambrian and Lower Silurian faunas, notwithstanding that nearly every species may be distinct, seems evident; but it may not be a closer one than that existing between the Upper Silurian and Devonian. This I infer from the following facts,—that in Bohemia, where the Cambrian or primordial fauna of Barrande is best developed, it consists mainly of Trilobites; and of this order more than two thirds of the genera and all the species, more than twenty in number, are, with one exception (*Agnostus pisiformis*), distinct from the Silurian. But M. Barrande observes that out of thirty-nine *Silurian* genera of Trilobites, no less than eleven pass upwards into the Devonian. If, therefore, we had only trilobites in the latter, its generic relationship to the Silurian fauna would appear greater than that of the Silurian to the Cambrian. And, though the details of the English rocks of this age are not yet fully known, the species at least appear all to be distinct. The same holds good with regard to the fossils of the Swedish strata, and, as we have seen, to those of America.

A distinctive character, therefore, is given to the fauna of this period, by which we seem to be carried one step further back into the history of organic life.

Supposed Period of Invertebrate Animals.

We have seen that in the upper part of the Silurian system a bone-bed occurs near Ludlow, in which the remains of fish are abundant, and amongst them some of a highly organized structure, referred to the genus *Onchus*. We are indebted to Sir R. Murchison for having first announced, in 1840, the discovery of these ichthyolites, and he then spoke of them as "the most ancient beings of their class." In his new and excellent work, entitled "Siluria" (p. 239.), he reverts to the opinion formerly expressed by him, and observes that the active researches of the last fourteen years in Europe and America "have failed to modify that generalization," adding "the Silurian system, therefore, may be regarded as representing a long early period, in which no vertebrated animals had been called into existence."

It is certainly a fact well worthy of our attention, that as yet no remains of fish are on record as coming from any stratum older than the base of the "Upper Ludlow." (See above, p. 436.) When we reflect on the number of Mollusks, Echinoderms, Corals, Trilobites, and other fossils already obtained from Silurian strata below "the Ludlow," we may well ask, whether any other set of fossiliferous formations were ever studied with equal diligence and over so vast an area without yielding some ichthyolites.

Nevertheless, we must be permitted to hesitate before we accept, even on such evidence, so sweeping a conclusion, as that the globe, for ages after it was habitable by all the great classes of invertebrata, remained wholly untenanted by vetebrate animals. In the first place, we must remember that we have detected no insects, or land-shells, or freshwater pulmoniferous mollusks, or terrestrial crustaceans, or plants (except fucoids), in rocks below the Upper Silurian. Their absence may admit of explanation, by supposing all the deposits of that era hitherto examined to have been formed in seas far from land or beyond the influence of rivers. Here and there indeed a shallow-water, or even a littoral deposit may have been met with, as in North Wales, for example, and North America; but, speaking generally, the Silurian deposits, as at present known, have certainly a more pelagic character than any other equally important formations.

It is a curious fact, and not perhaps a mere fortuitous coincidence, that the only stratum which has yielded the remains of land-plants is also the only one which has afforded the bones of fish. Bone-beds in general, such as that of the Lias near Bristol, those of the Trias near Stuttgardt, of the Carboniferous Limestone near Bristol and Armagh, and lastly that of the "Upper Ludlow," are remarkable for containing teeth and bones, much rolled and implying transportation from a distance. The association of the spores of Lycopodiaceæ (see p. 436.) with the Ludlow fish-bones shows that plants had been washed from some dry land, then existing, and had been drifted into a common submarine receptacle with the bones. More usually, however, the "Upper Ludlow," like the "Lower Silurian," is devoid of plants and equally destitute of ichthyolites.

It has been suggested that Cephalopoda were so abundant in the Silurian period that they may have discharged the functions of fish; to which we may reply that both classes coexisted in the Upper Silurian period, and both of them swarmed together in the Carboniferous and Liassic seas, as they do now in certain parts of the ocean. We may also suggest that we are too imperfectly acquainted with the distribution of scattered bones and teeth or the skeletons of dead fish on the floor of the existing ocean, to have a right to theorise with confidence on the absence of such relics over wide spaces at former eras.

They who in our own times have explored the bed of the sea inform us that it is in general as barren of vertebrate remains as the soil of a forest on which thousands of mammalia and reptiles may have flourished for centuries. In the summer of 1850, Prof. E. Forbes and Mr. McAndrew dredged the bed of the British seas from the Isle of Portland to the Land's End in Cornwall, and thence again to Shetland, recording and tabulating the numbers of the various organic bodies brought up by them in the course of 140 distinct dredgings, made at different distances from the shore, some a quarter of a mile, others forty miles distant. The list of species of marine invertebrate animals, whether Radiata, Mollusca, or Articulata, was very great, and the number of individuals enormous; but the only instances of vertebrate animals consisted of a few ear-bones and two or three vertebræ of fish, in all not above six relics.

It is still more extraordinary that Mr. McAndrew should have dredged the great "Ling Banks" or cod-fishery grounds off the Shetland Islands for shells without obtaining the bones or teeth of any dead fish, although he sometimes drew up live fish from the mud. This is the more singular, because there are some areas where recent fish-bones occur in the same northern seas in profusion, as I have shown in the "Principles of Geology" (see Index, "Vidal"); two bone-beds having been discovered by British hydrographers, one in the Irish sea, and the other in the sea near the Faroe Isles, the first of them two, and the other three and a half miles in length, where the lead brings up everywhere the vertebræ of fish from various depths between 45 to 235 fathoms. These may be compared to the Upper Ludlow bone-bed; and on the floor of the ocean of our times, as on that of the Silurian epoch, there are other wide spaces where no bones are imbedded in mud or sand.

It may be true, though it sounds somewhat like a paradox, that fish leave behind them no memorials of their presence in places where they swarm and multiply freely; whereas currents may drift their bones in great numbers to regions wholly destitute of living fish. Such a state of things would be quite analogous to what takes place on the habitable land, where, instead of the surface becoming encumbered with heaps of skeletons of quadrupeds, birds, and land-reptiles, all solid bony substances are removed after death by chemical processes, or by the digestive powers of predaceous beasts; so that, if at some future period a geologist should seek for monuments of the former existence of such creatures, he must look anywhere rather than in the area where they flourished. He must search for them in spots which were covered at the time with water, and to which some bones or carcases may have been occasionally carried by floods and permanently buried in sediment.

In the annexed Table, a few dates are set before the reader of the discovery of different classes of animals in ancient rocks, to enable him to perceive at a glance how gradual has been our progress in tracing back the signs of Vertebrata to formations of high antiquity. Such facts may be useful in warning us not to assume too hastily that the point which our retrospect may have reached at the present moment can be regarded as fixing the date of the first introduction of any one class of beings upon the earth.

Dates of the Discovery of different Classes of Fossil Vertebrata; showing the gradual Progress made in tracing them to Rocks of higher Antiquity.

	Year.	Formations.	Geographical Localities.
Mammalia.	1798.	Middle Eocene (or B. i. p. 223.).	Paris (Gypsum of Montmartre).[1]
	1818.	Lower Oolite.	Stonesfield.[2]
	1847.	Upper Trias.	Stuttgardt.[3]
Aves.	1782.	Middle Eocene (or B. i. p. 223.).	Paris (Gypsum of Montmartre).[4]
	1839.	Lower Eocene.	London (Sheppey Clay).[5]
Reptilia.	1710.	Permian (or Zechstein).	Thuringia.[6]
	1844.	Carboniferous.	Saarbruck, near Treves.[7]
	1852.	Upper Devonian.	Elgin.[8]
Pisces.	1709.	Permian (or Kupfer-schiefer).	Thuringia.[9]
	1793.	Carboniferous (Mountain Limestone).	Glasgow.[10]
	1828.	Devonian.	Caithness.[11]
	1840.	Upper Silurian.	Ludlow.[12]

[1] Cuvier (George). Bulletin Soc. Philom. xx. Scattered bones were found in the gypsum some years before; but they were determined osteologically, and their true geological position was assigned to them in this memoir.

[2] In 1818, Cuvier, visiting the Museum of Oxford, decided on the mammalian character of a jaw from Stonesfield. See also above, p. 312.

[3] Plieninger, Prof. See above, p. 342.

[4] M. Darcet discovered, and Lamanon figured, as a fossil bird, some remains from Montmartre, afterwards recognized as such by Cuvier (Ossemens Foss., Art. "Oiseaux").

[5] Owen, Prof., Geol. Trans. 2nd Ser. vol. vi. p. 203., 1839. The fossil bird discovered in the same year in the slates of Glaris in the Alps, and at first referred to the chalk, is now supposed to belong to the Nummulitic beds, and may therefore be of newer date than the Sheppey Clay.

[6] The fossil monitor of Thuringia (*Protorosaurus Speneri*, V. Meyer) was figured by Spener, of Berlin, in 1810. (Miscel. Berlin.)

[7] See above, p. 401.

[8] See above, p. 416.

[9] Memorabilia Saxoniæ Subterr., Leipsic, 1709.

[10] History of Rutherglen, by Rev. David Ure, 1793.

[11] Sedgwick and Murchison, Geol. Trans., 2nd Ser. vol. iii. p. 141., 1828.

[12] Sir R. Murchison. See above, p. 435.

Obs. The evidence derived from footprints, though often to be relied on, is omitted in the above table, as being less exact than that founded on bones and teeth.

How many living writers are there who, before the year 1844, generalized fearlessly on the non-existence of reptiles before the Permian era! Yet, in the course of ten years, they have lived to see the earliest known date of the creation of reptiles carried back successively, first to the Carboniferous, and then to the Upper Devonian periods. Before the year 1818, it was the popular belief that the Palæotherium of the Paris gypsum and its associates were the first warm-blooded quadrupeds that ever trod the surface of this planet.

So fixed was this idea in the minds of the majority of naturalists, that, when at length the Stonesfield Mammalia awoke from a slumber of three or four great periods, the apparition failed to make them renounce their creed.

> "Unwilling I my lips unclose—
> Leave, oh, leave me to repose."

First, the antiquity of the rock was called in question; and then the mammalian character of the relics. Even long after all controversy was set at rest on these points, the real import of the new revelation, as bearing on the doctrine of progressive development, was far from being duly appreciated.

It is clear that the first two or three species, encountered in any country or in the rocks of any epoch, cannot be taken as a type or standard for measuring the grade of organization of any terrestrial fauna, ancient or modern. Suppose that the two or three oolitic species first brought to light had really been all marsupial, as was for a time erroneously imagined, this would not have borne out the inference which some attempted to deduce from it, namely, that the time had not yet come for the creation of the placental tribes. Or, if when some monodelph were at last actually recognized (at Stonesfield), they happened to be of diminutive size, and to belong to the insectivora, we are not entitled to deduce from such data that the oolitic fauna ranked low in the general scale, as the insectivora may do in an existing fauna. The real significance of the discoveries alluded to arises from the aid they afford us in estimating the true value of negative evidence, when brought to bear on certain speculative questions. Every zoologist will admit that between the first creation and the final extinction of any one of the five* oolitic mammalia now known there were many successive generations; and, if the geographical range of each species was limited (which we have no right to assume), still there must have been several hundred individuals in each generation, and probably, when the species reached its maximum, several thousands. When, therefore, we encounter for the first time in 1854 two or three jaws of a *Spalacotherium* in the Purbeck limestone, after countless specimens of Mollusca and Crustacea, and hundreds of insects, fish, and reptiles had been previously collected from the same beds, we are not simply taught that these individual quadrupeds flourished at the era in question, but that thousands, perhaps hundreds of thousands, of the same species peopled the land without leaving behind them any trace of their existence, whether in the shape of fossil bones or footprints; or, if they left any traces, these have eluded a long and most persevering search.

Moreover, we must never forget how many of the dates given in the

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* I had written *four*, but while this sheet was passing through the press (Sept. 26, 1854) the discovery of another species of insectivorous mammal from Stonesfield was announced to the British Association at Liverpool by Mr. Charlesworth, who has given to it the name of *Stereognathus ooliticus*. It is more than twice the size of any of the species previously obtained from the same formation. We have now, therefore, including the recently found Spalacotherium of Purbeck (see p. 296.), five British mammalia from the oolite.

above table (p. 460.), are due to British skill and energy, Great Britain being still the only country in which mammalia have been found in Oolitic rocks; the only region where any reptiles have been detected in strata as old as the Devonian; the only one wherein the bones of birds have been traced back as far as the London Clay. And, if geology had been cultivated with less zeal in our island, we should know nothing as yet of two extensive assemblages of tertiary mammalia of higher antiquity than the fauna of the Paris Gypsum (already cited as having once laid claim to be the earliest that ever flourished on the earth)—namely, first, that of the Headon series (see above, p. 213.); and, secondly, one long prior to it in date, and antecedent to the London Clay.* This last has already afforded us indications of Quadrumana, Cheiroptera, Pachydermata, and Marsupialia (see p. 218.). How then can we doubt, if every area on the globe were to be studied with the same diligence,—if all Europe, Asia, Africa, America, and Australia were equally well known, that every date assigned by us in the above Table for the earliest recorded appearance of fish, reptiles, birds, and mammals would have to be altered? Nay, if one other area, such as part of Spain, of the size of England and Scotland, were subjected to the same scrutiny (and we are still very imperfectly acquainted even with Great Britain), each class of Vertebrata would probably recede one or more steps farther back into the abyss of time: fish might penetrate into the Lower Silurian,—reptiles into the Lower Devonian,—mammalia into the Lower Trias,—birds into the Chalk or Oolite,—and, if we turn to the Invertebrata, Trilobites and Cephalopods might descend into the Lower Cambrian,—and some stray zoophyte, like the *Oldhamia*, into rocks now styled "azoic."

Yet, after these and many more analogous revisions of the Table, it might still be just as easy as now to found a theory of progressive development on the new set of positive and negative facts thus established; for the order of chronological succession in the different classes of fossil animals would probably continue the same as now;—in other words, our success in tracing back the remains of each class to remote eras would be greatest in fishes, next in reptiles, next in mammalia, and least in birds. That we should meet with ichthyolites more universally at each era, and at greater depths in the series, than any other class of fossil vertebrata, would follow partly from our having as paleontologists to do chiefly with strata of marine origin, and partly, because bones of fish, however partial and capricious their distribution on the bed of the sea, are nevertheless more easily met with than those of reptiles or mammalia. In like manner, the extreme rarity of birds in recent and Pliocene strata, even in those of freshwater origin, might lead us to anticipate that their remains would be obtained with the greatest difficulty in the older rocks, as the Table proves to be the case,—even in tertiary

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* A bird's bone is recorded as having been lately found in the Woolwich beds (beneath the London clay), by Mr. Prestwich; Geol. Quart. Journ. vol. x. p. 157.

strata, wherein we can more readily find deposits formed in lakes and estuaries.

The only incongruity between the geological results, and those which our dredging experiences might have led us to anticipate *à priori*, consists in the frequency of fossil reptiles, and the comparative scarcity of mammalia. It would appear that during all the secondary periods, not even excepting the newest part of the cretaceous, there was a greater development of reptile life than is now witnessed in any part of the globe. The preponderance of this class over the mammalia depended probably on climatal and geographical conditions, for we can scarcely refer it to "progressive development," by which the vertebrate type was steadily improving, or becoming more perfect, as Time rolled on. We cannot shut our eyes to the positive proofs now obtained of the creation of mammalia before the excess of reptiles had ceased,—nay, apparently before it had even reached its maximum.

In conclusion, I shall simply express my own conviction that we are still on the mere threshold of our inquiries; and that, as in the last fifty years, so in the next half-century, we shall be called upon repeatedly to modify our first opinions respecting the range in time of the various classes of fossil Vertebrata. It would therefore be premature to generalize at present on the non-existence, or even on the scarcity of Vertebrata, whether terrestrial or aquatic, at periods of high antiquity, such as the Silurian and Cambrian.*

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* For observations on the rarity of air-breathers in the coal, see above, p. 405.

CHAPTER XXVIII.

VOLCANIC ROCKS.

Trap rocks—Name, whence derived—Their igneous origin at first doubted—Their general appearance and character—Volcanic cones and craters, how formed—Mineral composition and texture of volcanic rocks—Varieties of felspar—Hornblende and augite—Isomorphism—Rocks, how to be studied—Basalt, trachyte, greenstone, porphyry, scoria, amygdaloid, lava, tuff—Agglomerate—Laterite—Alphabetical list, and explanation of names and synonyms, of volcanic rocks—Table of the analyses of minerals most abundant in the volcanic and hypogene rocks.

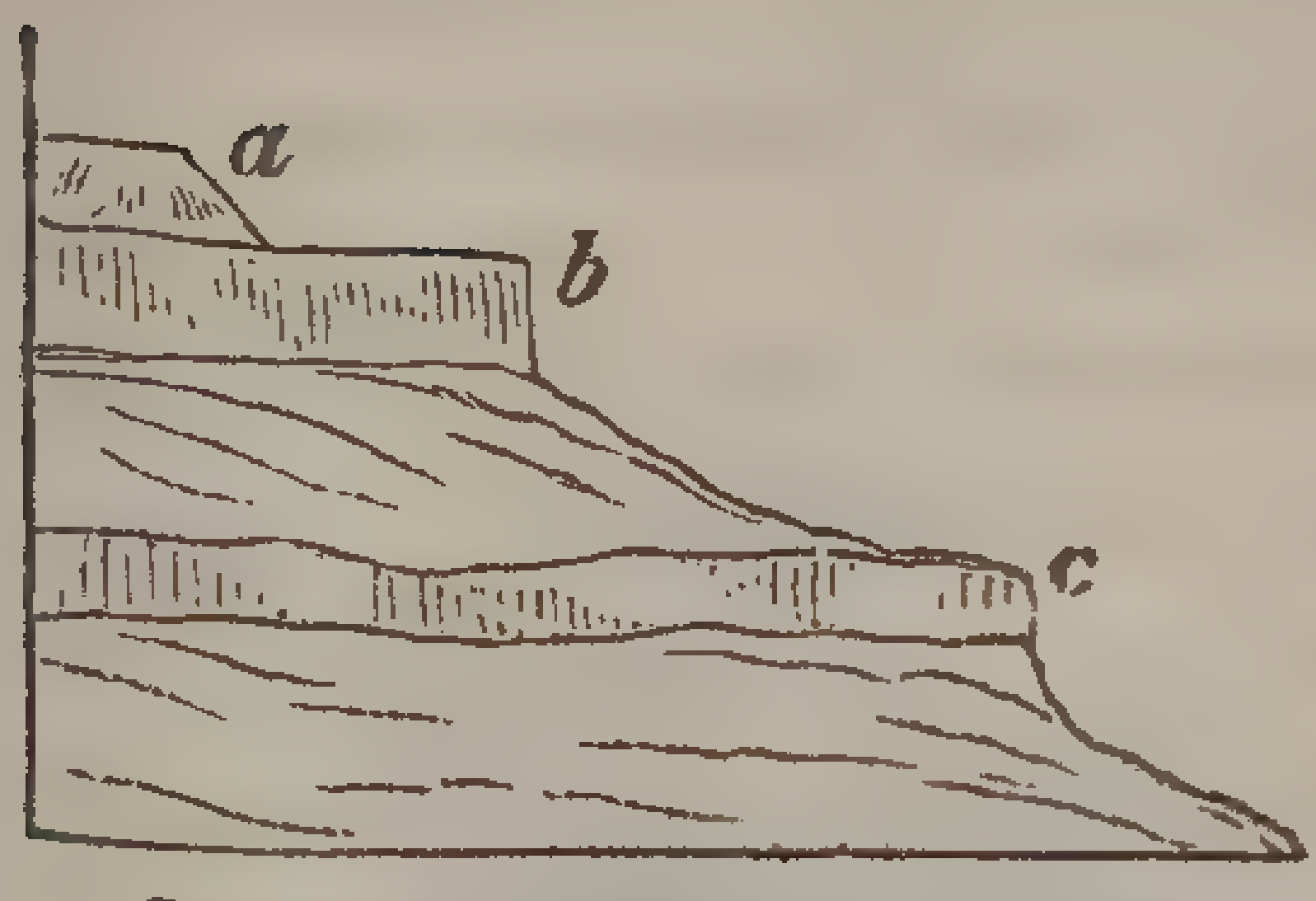
THE aqueous or fossiliferous rocks having now been described, we have next to examine those which may be called volcanic, in the most extended sense of that term. Suppose *a a* in the annexed diagram, to represent the crystalline formations, such as the granitic and metamorphic; *b b* the fossiliferous strata; and *c c* the volcanic rocks. These last are sometimes found, as was explained in the first chapter, breaking through *a* and *b*, sometimes overlying both, and occasionally alternating with the strata *b b*. They also are seen, in some instances, to pass insensibly into the unstratified division of *a*, or the Plutonic rocks.

Fig. 619.

a. Hypogene formations, stratified and unstratified.
b. Aqueous formations. *c*. Volcanic rocks.

When geologists first began to examine attentively the structure of the northern and western parts of Europe, they were almost entirely ignorant of the phenomena of existing volcanos. They found certain rocks, for the most part without stratification, and of a peculiar mineral composition, to which they gave different names, such as basalt, greenstone, porphyry, and amygdaloid. All these, which were recognized as belonging to one family, were called "trap" by Bergmann, from *trappa*, Swedish for a flight of steps—a name since adopted very generally into the nomenclature of the science; for it was observed that many rocks of this class occurred in great tabular masses of unequal extent, so as to form a succession of terraces or steps on the sides of hills. This configuration appears to be derived from two causes. First, the abrupt original terminations of sheets of melted matter, which have spread, whether on the land or bottom of the sea, over a level surface. For we know, in the case of lava flowing from a volcano, that a stream, when it has ceased to flow, and grown solid, very commonly ends in a steep slope, as at *a*, fig. 620. But, secondly, the step-like appearance arises more frequently from the mode in which horizontal masses of igneous rock, such as *b c*, intercalated between aqueous strata, or showers of volcanic dust and ashes, have, subsequently to their origin, been exposed, at different heights, by denudation. Such an outline, it is true, is not peculiar to trap rocks; great beds of limestone, and other hard kinds of stone, often presenting similar terraces and precipices: but these are usually on a smaller scale, or less numerous, than the volcanic *steps*, or form less decided features in the landscape, as being less distinct in structure and composition from the associated rocks.

Fig. 620.



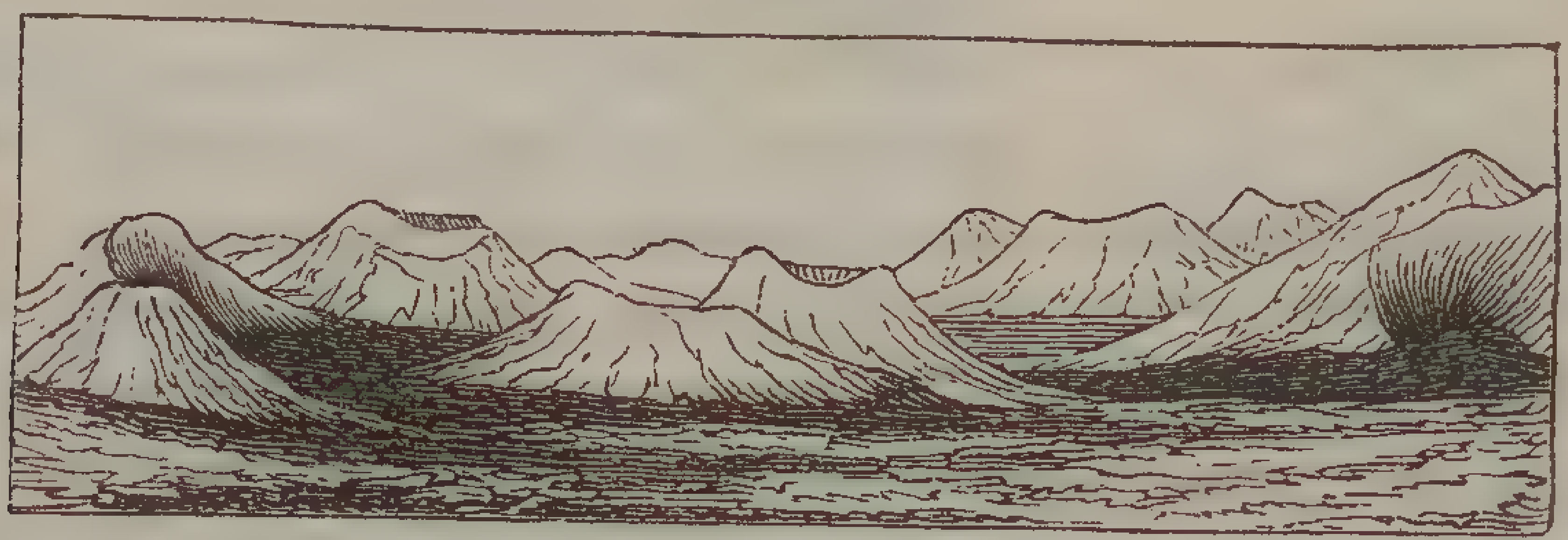
Step-like appearance of trap.

Although the characters of trap rocks are greatly diversified, the beginner will easily learn to distinguish them as a class from the aqueous formations. Sometimes they present themselves, as already stated, in tabular masses, which are not divided by horizontal planes of stratification in the manner of sedimentary deposits. Sometimes they form chains of hills often conical in shape. Not unfrequently they are seen as "dikes" or wall-like masses, intersecting fossiliferous beds. The rock is occasionally columnar, the columns sometimes decomposing into balls of various sizes, from a few inches to several feet in diameter. The decomposing surface very commonly assumes a coating of a rusty iron colour, from the oxidation of ferruginous matter, so abundant in the traps in which augite or hornblende occur; or, in the felspathic varieties of trap, it acquires a white opaque coating, from the bleaching of the mineral called felspar. On examining any of these volcanic rocks, where they have not suffered disintegration, we rarely fail to detect a crystalline arrangement in one or more of the component minerals. Sometimes the texture of the mass is cellular or porous, or we perceive that it has once been full of pores and cells, which have afterwards become filled with carbonate of lime, or other infiltrated mineral.

Most of the volcanic rocks produce a fertile soil by their disintegration. It seems that their component ingredients, silica, alumina, lime, potash, iron, and the rest, are in proportions well fitted for the growth of vegetation. As they do not effervesce with acids, a deficiency of calcareous matter might at first be suspected; but although *the carbonate* of lime is rare, except in the nodules of amygdaloids, yet it will be seen that lime sometimes enters largely into the composition of augite and hornblende. (See Table, p. 479.)

Cones and Craters.—In regions where the eruption of volcanic matter has taken place in the open air, and where the surface has never since been subjected to great aqueous denudation, cones and craters constitute the most striking peculiarity of this class of formations. Many hundreds of these cones are seen in central France, in the ancient provinces of Auvergne, Velay, and Vivarais, where they observe, for the most part, a linear arrangement, and form chains of hills. Although none of the eruptions have happened within the historical era, the streams of lava may still be traced distinctly descending from many of the craters, and following the lowest levels of the existing valleys. The origin of the cone and crater-shaped hill is well understood, the growth of many having been watched during volcanic eruptions. A chasm or fissure first opens in the earth, from which great volumes of steam and other gases are evolved. The explosions are so violent as to hurl up into the air fragments of broken stone, parts of which are shivered into minute atoms. At the same time melted stone or *lava* usually ascends through the chimney or vent by which the gases make their escape. Although extremely heavy, this lava is forced up by the expansive power of entangled gaseous fluids, chiefly steam or aqueous vapour, exactly in the same manner as water is made to boil over the edge of a vessel when steam has been generated at the bottom by heat. Large quantities of the lava are also shot up into the air, where it separates into fragments, and acquires a spongy texture by the sudden enlargement of the included gases, and thus forms *scoriæ*, other portions being reduced to an impalpable powder or dust. The showering down of the various ejected materials round the orifice of eruption gives rise to a conical mound, in which the successive envelopes of sand and scoriæ form layers, dipping on all sides from a central axis. In the mean time a hollow, called a *crater*, has been kept open in the middle of the mound by the continued passage upwards of steam and other gaseous fluids. The lava sometimes flows over the edge of the crater, and thus thickens and strengthens the sides of the cone; but sometimes it breaks down the cone on one side (see fig. 621.), and often it flows out from a fissure at the base of the hill, or at some distance from its base.*

Fig. 621.



Part of the chain of extinct volcanos called the Monts Dome, Auvergne. (Scrope.)

Composition and nomenclature.—Before speaking of the connection between the products of modern volcanos and the rocks usually styled trappean, and before describing the external forms of both, and the manner and position in which they occur in the earth's crust, it will be desirable to treat of their mineral composition and names. The varieties most frequently spoken of are basalt and trachyte, to which

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* For a description and theory of active volcanos, see Principles of Geology, chaps. xxiv. *et seq.* & xxxii.

dolerite, greenstone, clinkstone, and others might be added; while those founded chiefly on peculiarities of texture, are porphyry, amygdaloid, lava, volcanic breccia or agglomerate, tuff, scoriæ, and pumice. It may be stated generally, that all these are mainly composed of two minerals, or families of simple minerals, *felspar* and *hornblende;* but the felspar preponderates greatly even in those rocks to which the hornblendic mineral imparts its distinctive character and prevailing colour.

The two minerals alluded to may be regarded as two groups, rather than species. Felspar, for example, may be, first, common felspar (often called Orthoclase), that is to say, potash-felspar, in which the predominant alkali is potash (see Table, p. 479.); or, secondly, albite, that is to say, soda-felspar, where the predominant alkali is soda instead of potash; or, thirdly, Oligoclase; or, fourthly, Labrador-felspar (Labradorite), which differs not only in its iridescent hues, but also in its angle of fracture or cleavage, and its composition. We also read much of two other kinds, called glassy felspar and compact felspar, which, however, cannot rank as varieties of equal importance, for both the albitic and common felspar appear sometimes in transparent or *glassy* crystals; and as to compact felspar, it is a compound of a less definite nature, sometimes containing largely both soda and potash; and which might be called a felspathic paste, being the residuary matter after portions of the original matrix have crystallized. The more recent analyses have shown that all the varieties or species of felspar may contain both potash and soda, although in some of them the one, and in others the other alkali greatly prevails.

The *hornblendic* group consists principally of two varieties; first, hornblende, and, secondly, augite, which were once regarded as very distinct, although now some eminent mineralogists are in doubt whether they are not one and the same mineral, differing only as one crystalline form of native sulphur differs from another.

The history of the changes of opinion on this point is curious and instructive. Werner first distinguished augite from hornblende; and his proposal to separate them obtained afterwards the sanction of Haüy, Mohs, and other celebrated mineralogists. It was agreed that the form of the crystals of the two species were different, and their structure, as shown by *cleavage,* that is to say, by breaking or cleaving the mineral with a chisel, or a blow of the hammer, in the direction in which it yields most readily. It was also found by analysis that augite usually contained more lime, less alumina, and no fluoric acid; which last, though not always found in hornblende, often enters into its composition in minute quantity. In addition to these characters, it was remarked as a geological fact, that augite and hornblende are very rarely associated together in the same rock; and that when this happened, as in some lavas of modern date, the hornblende occurs in the mass of the rock, where crystallization may have taken place more slowly, while the augite merely lines cavities where the crystals may have been produced rapidly. It was also remarked, that in the crystalline slags of furnaces, augitic forms were frequent, the hornblendic entirely absent; hence it was conjectured that hornblende might be the result of slow, and augite of rapid cooling. This view was confirmed by the fact, that Mitscherlich and Berthier were able to make augite artificially, but could never succeed in forming hornblende. Lastly, Gustavus Rose fused a mass of hornblende in a porcelain furnace, and found that it did not, on cooling, assume its previous shape, but invariably took that of augite. The same mineralogist observed certain crystals in rocks from Siberia which presented a hornblende *cleavage*, while they had the external form of augite.

If, from these data, it is inferred that the same substance may assume the crystalline forms of hornblende or augite indifferently, according to the more or less rapid cooling of the melted mass, it is nevertheless certain that the variety commonly called augite, and recognised by a peculiar crystalline form, has usually more lime in it, and less alumina, than that called hornblende, although the quantities of these elements do not seem to be always the same. Unquestionably the facts and experiments above mentioned show the very near affinity of hornblende and augite; but even the convertibility of one into the other, by melting and recrystallizing, does not perhaps demonstrate their absolute identity. For there is often some portion of the materials in a crystal which are not in perfect chemical combination with the rest. Carbonate of lime, for example, sometimes carries with it a considerable quantity of silex into its own form of crystal, the silex being mechanically mixed as sand, and yet not preventing the carbonate of lime from assuming the form proper to it. This is an extreme case, but in many others some one or more of the ingredients in a crystal may be excluded from perfect chemical union; and after fusion, when the mass recrystallizes, the same elements may combine perfectly or in new proportions, and thus a new mineral may be produced. Or some one of the gaseous elements of the atmosphere, the oxygen for example, may, when the melted matter reconsolidates, combine with some one of the component elements.

The different quantity of the impurities or refuse above alluded to, which may occur in all but the most transparent and perfect crystals, may partly explain the discordant results at which experienced chemists have arrived in their analysis of the same mineral. For the reader will find that crystals of a mineral determined to be the same by physical characters, crystalline form, and optical properties, have often been declared by skilful analyzers to be composed of distinct elements. (See the table at p. 479.) This disagreement seemed at first subversive of the atomic theory, or the doctrine that there is a fixed and constant relation between the crystalline form and structure of a mineral and its chemical composition. The apparent anomaly, however, which threatened to throw the whole science of mineralogy into confusion, was in a great degree reconciled to fixed principles by the discoveries of Professor Mitscherlich at Berlin, who ascertained that the composition of the minerals which had appeared so variable, was governed by a general law, to which he gave the name of *isomorphism* (from ισος, *isos*, equal, and μορφη, *morphe*, form). According to this law, the ingredients of a given species of mineral are not absolutely fixed as to their kind and quality; but one ingredient may be replaced by an equivalent portion of some analogous ingredient. Thus, in augite, the lime may be in part replaced by portions of protoxide of iron, or of manganese, while the form of the crystal, and the angle of its cleavage planes, remain the same. These vicarious substitutions, however, of particular elements cannot exceed certain defined limits.

Pyroxene, a name of Haüy's, is often used for augite in descriptions of volcanic rocks. It is properly, according to M. Delesse, a general name, under which Augite, Diallage, and Hypersthene may be united, for these three are varieties of one and the same mineral species, having the same chemical formula with variable bases.

Amphibole is in like manner a general term under which Hornblende and Actinolite may be united.

Having been led into this digression on some recent steps made in the progress of mineralogy, I may here observe that the geological student must endeavour as soon as possible to familiarize himself with the characters of five at least of the most abundant simple minerals of which rocks are composed. These are felspar, quartz, mica, hornblende, and carbonate of lime. This knowledge cannot be acquired from books, but requires personal inspection, and the aid of a teacher. It is well to accustom the eye to know the appearance of rocks under the lens. To learn to distinguish felspar from quartz is the most important step to be first aimed at. In general we may know the felspar because it can be scratched with the point of a knife, whereas the quartz, from its extreme hardness, receives no impression. But when these two minerals occur in a granular and uncrystallized state, the young geologist must not be discouraged if, after considerable practice, he often fails to distinguish them by the eye alone. If the felspar is in crystals, it is easily recognized by its cleavage; but when in grains the blow-pipe must be used, for the edges of the grains can be rounded in the flame, whereas those of *quartz* are infusible. If the geologist is desirous of detecting the varieties of felspar above enumerated, or distinguishing hornblende from augite, it will often be necessary to use the reflecting goniometer as a test of the angle of cleavage, and shape of the crystal. The use of this instrument will not be found difficult.

The external characters and composition of the felspars are extremely different from those of augite or hornblende; so that the volcanic rocks in which either of these minerals play a conspicuous part are easily recognizable. But there are mixtures of the two elements in very different proportions, the mass being sometimes exclusively composed of felspar, and at other times largely of augite. Between the two extremes there is almost every intermediate gradation; yet certain compounds prevail so extensively in nature, and preserve so much uniformity of aspect and composition, that it is useful in geology to regard them as distinct rocks, and to assign names to them, such as basalt, greenstone, trachyte, and others presently to be mentioned.

Basalt. — As an example of rocks in which augite is a conspicuous ingredient, basalt may first be mentioned. Although we are more familiar with this term than with that of any other kind of trap, it is difficult to define it, the name having been used so comprehensively, and sometimes so vaguely. It has been generally applied to any trap rock of a black, bluish, or leaden-grey colour, having a uniform and compact texture. Most strictly, it consists of an intimate mixture of felspar, augite, and iron, to which a mineral of an olive-green colour, called olivine, is often superadded, in distinct grains or nodular masses. The iron is usually magnetic, and is often accompanied by another metal, titanium. The term "Dolerite" is now much used for this rock, when the felspar is of the variety called Labradorite, as in the lavas of Etna. Basalt, according to Dr. Daubeny, in its more strict sense, is composed of "an intimate mixture of augite with a zeolitic mineral which appears to have been formed out of Labradorite by the addition of water, the presence of water being in all *zeolites* the cause of that bubbling up under the blowpipe, to which they owe their appellation.* Of late years the analyses of M. Delesse and other eminent mineralogists have shown that the opinion once entertained, that augite was the prevailing mineral in basalt, or even in the most augitic trap rocks, must be abandoned. Although its presence gives to these rocks their distinctive character as contrasted with trachytes, still the principal element in their composition is felspar.

Augite rock has, indeed, been defined by Leonhard as being made up principally or wholly of augite†, and in some veinstones, says Delesse, such a rock may be found; but the greater part of what passes by the name of augite rock is more rich in green felspar than in augite. *Amphibolite*, in like manner, or *Hornblende rock*, is a trap of the basaltic family, in which there is much hornblende, and in which this mineral has been supposed to predominate; but Delesse finds, by analysis, that the felspar may be in excess, the base being felspathic.

In some varieties of basalt the quantity of olivine is very great; and as this mineral differs but slightly in its chemical composition from serpentine (see Table of Analyses, p. 479.), containing even a larger proportion of magnesia than serpentine, it has been suggested with much probability that in the course of ages some basalts highly charged with olivine may be turned, by metamorphic action, into serpentine.

Trachyte. — This name, derived from τραχυς, rough, has been given to the felspathic class of volcanic rocks which have a coarse, cellular paste, rough and gritty to the touch. This paste has commonly been supposed to consist chiefly of albite, but according

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* Volcanos, 2d ed. p. 18.

† Mineralreich, 2d ed. p. 85.

to M. Delesse it is variable in composition, its prevailing alkali being soda. Through the base are disseminated crystals of glassy felspar, mica, and sometimes quartz and hornblende, although in the trachyte, properly so called, there is no quartz. The varieties of felspar which occur in trachyte are trisilicates, or those in which the silica is to the alumina in the proportion of three atoms to one.*

Trachytic Porphyry, according to Abich, has the ordinary composition of trachyte, with quartz superadded, and without any augite or titaniferous iron. *Andesite* is a name given by Gustavus Rose to a trachyte of the Andes, which contains the felspar called Andesin, together with glassy felspar (orthoclase) and hornblende disseminated through a dark-coloured base.

Clinkstone, or *Phonolite.* — Among the felspathic products of volcanic action, this rock is remarkable for its tendency to lamination, which is sometimes such that it affords tiles for roofing. It rings when struck with the hammer, whence its name; is compact, and usually of a greyish blue or brownish colour; is variable in composition, but almost entirely composed of felspar, and in some cases, according to Gmelin, of felspar and mesotype. When it contains disseminated crystals of felspar, it is called *Clinkstone porphyry.*

Greenstone is the most abundant of those volcanic rocks which are intermediate in their composition between the Basalts and Trachytes. The name has usually been extended to all granular mixtures, whether of hornblende and felspar, or of augite and felspar. The term *diorite* has been applied exclusively to compounds of hornblende and felspar. According to the analyses of Delesse and others, the chief cause of the green colour, in most greenstones, is not green hornblende nor augite, but a green siliceous base, very variable and indefinite in its composition. The dark colour, however, of diorite is usually derived from disseminated plates of hornblende.

The Basalts contain a smaller quantity of silica than the Trachytes, and a larger proportion of lime and magnesia. Hence, independently of the frequent presence of iron, basalt is heavier. Abich has therefore proposed that we should weigh these rocks, in order to appreciate their composition in cases where it is impossible to separate their component minerals. Thus, the variety of basalt called dolerite, which contains 53 per cent. of silica, has a specific gravity of 2·86; whereas trachyte, which has 66 per cent. of silica, has a sp. gr. of only 2·68; trachytic porphyry, containing 69 per cent. of silica, a sp. gr. of only 2·58. If we then take a rock of intermediate composition, such as that prevailing in the Peak of Teneriffe, which Abich calls Trachyte-dolerite, its proportion of silica being intermediate, or 58 per cent., it weighs 2·78, or more than trachyte, and less than basalt.† The basalts are generally dark in colour, sometimes almost black, whereas the trachytes are grey, and even occasionally white. As compared with the granitic rocks, basalts and trachytes contain both of them more soda in their composition, the potash-felspars

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* Dr. Daubeny on Volcanos, 2d ed. pp. 14, 15.

† Ibid.

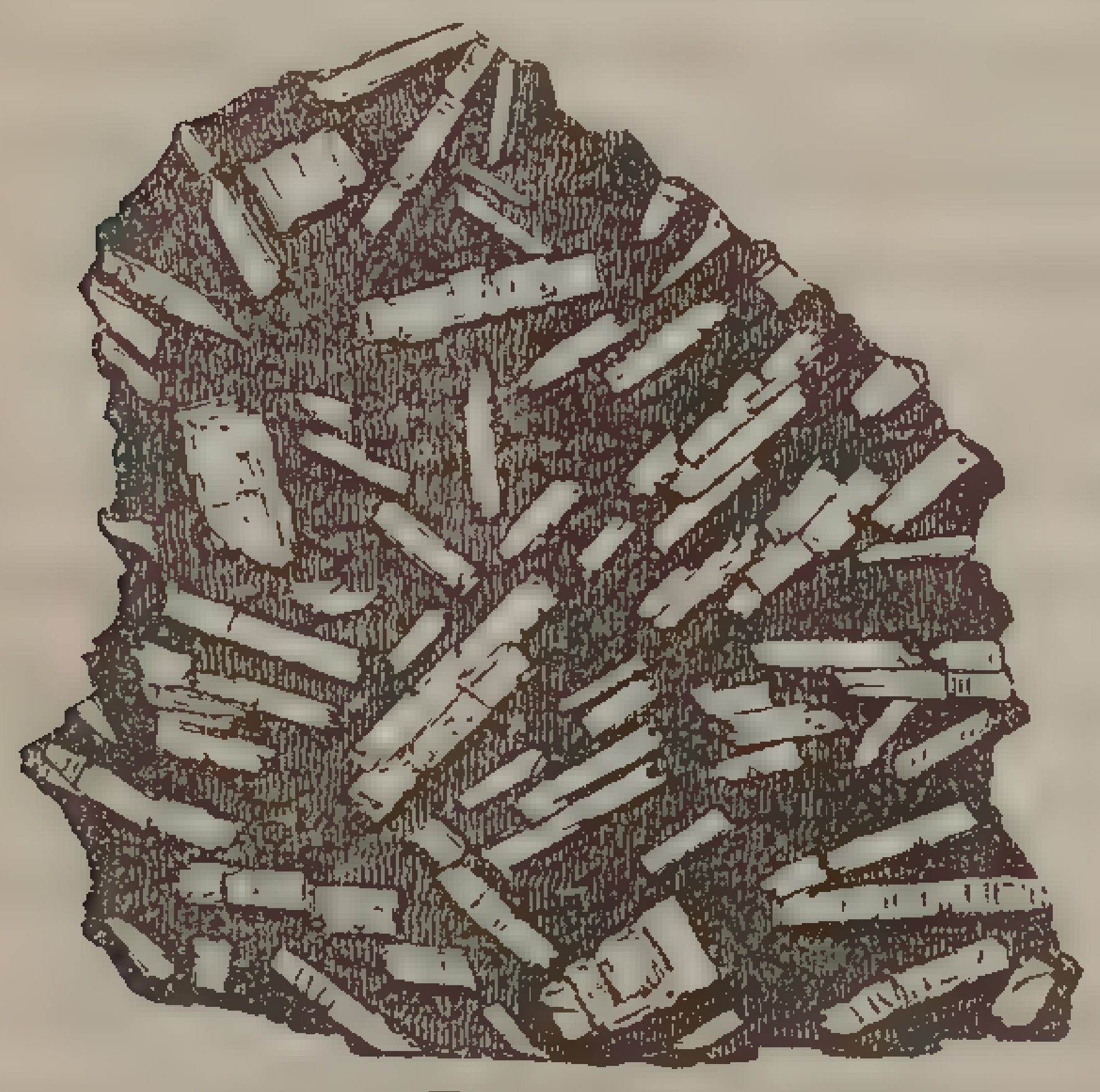
being generally abundant in the granites. The volcanic rocks moreover, whether basaltic or trachytic, contain less silica than the granites, in which last the excess of silica has gone to form quartz. This mineral, so conspicuous in granite, is usually wanting in the volcanic formations, and never predominates in them.

The fusibility of the igneous rocks generally exceeds that of other rocks, for the alkaline matter and lime which commonly abound in their composition serve as a flux to the large quantity of silica, which would be otherwise so refractory an ingredient.

We may now pass to the consideration of those igneous rocks, the characters of which are founded on their form rather than their composition.

Porphyry is one of this class, and very characteristic of the volcanic formations. When distinct crystals of one or more minerals are scattered through an earthy or compact base, the rock is termed a porphyry (see fig. 622.). Thus trachyte is porphyritic; for in it, as in many modern lavas, there are crystals of felspar; but in some porphyries the crystals are of augite, olivine, or other minerals. If the base be greenstone, basalt, or pitchstone, the rock may be denominated greenstone-porphyry, pitchstone-porphyry, and so forth. The old classical type of this form of rock is the red porphyry of Egypt, or the well known "Rosso antico." It consists, according to Delesse, of a red felspathic base in which are disseminated rose-coloured crystals of the felspar called oligoclase, with some plates of blackish hornblende and grains of oxidized iron-ore (fer oligiste). *Red quartziferous porphyry* is a much more siliceous rock, containing about 70 or 80 per cent. of silex, while that of Egypt has only 62 per cent.

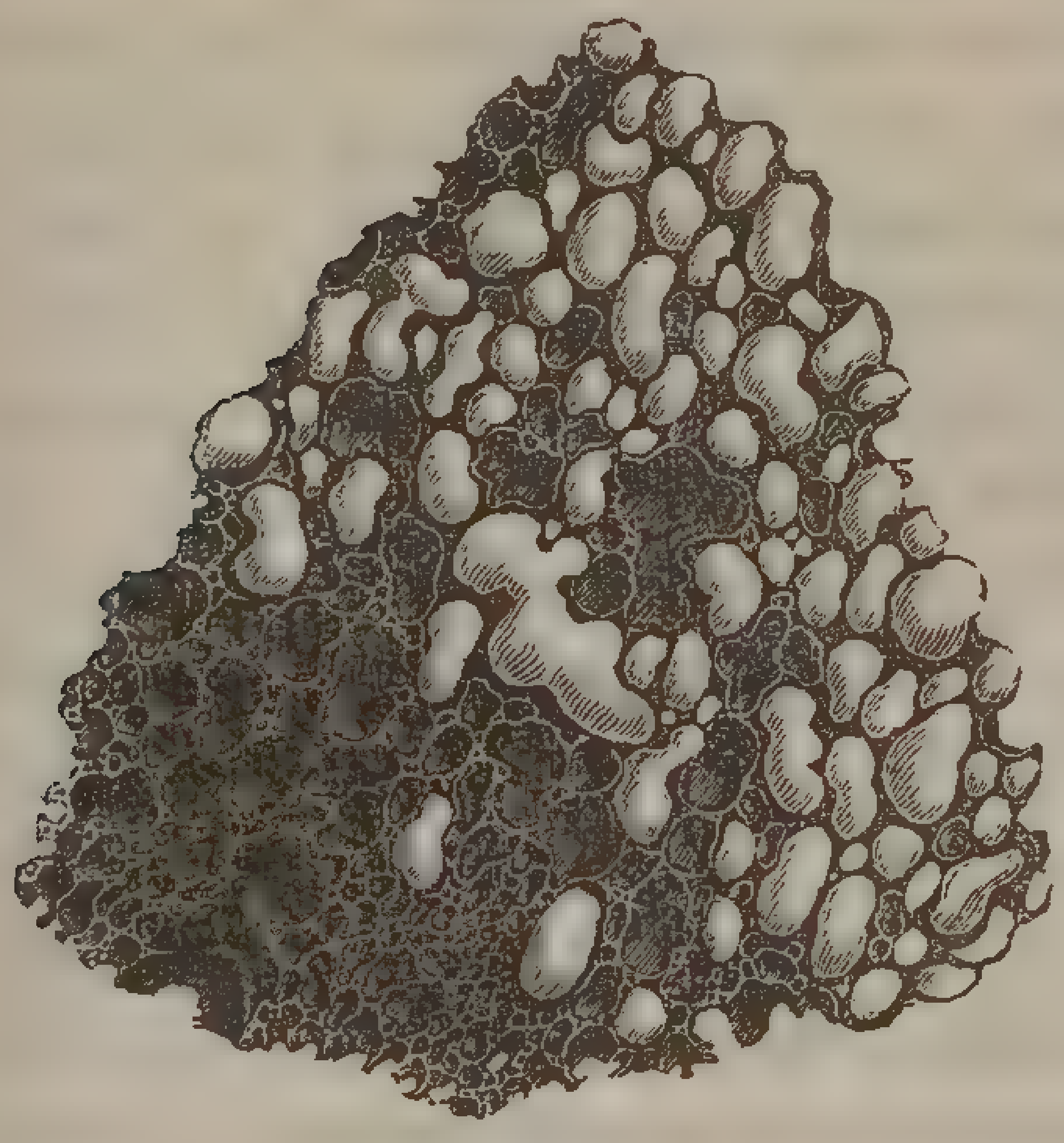
Fig. 622.



Porphyry.
White crystals of felspar in a dark base of hornblende and felspar.

Amygdaloid. — This is also another form of igneous rock, admitting of every variety of composition. It comprehends any rock in which round or almond-shaped nodules of some mineral, such as agate, calcedony, calcareous spar, or zeolite, are scattered through a base of wacké, basalt, greenstone, or other kind of trap. It derives its name from the Greek word *amygdala*, an almond. The origin of this structure cannot be doubted, for we may trace the process of its formation in modern lavas. Small pores or cells are caused by bubbles of steam and gas confined in the melted matter. After or during consolidation, these empty spaces are gradually filled up by matter separating from the mass, or infiltered by water permeating the rock. As these bubbles have been sometimes lengthened by the flow of the lava before it finally cooled, the contents of such cavities have the form of almonds. In some of the amygdaloidal traps of Scotland, where the nodules have decomposed, the empty cells are seen to have a glazed or vitreous coating, and in this respect exactly resemble scoriaceous lavas, or the slags of furnaces.

Fig. 623.



Scoriaceous lava in part converted into an amygdaloid.
Montagne de la Veille, Department of Puy de Dome, France.

The annexed figure represents a fragment of stone taken from the upper part of a sheet of basaltic lava in Auvergne. One half is scoriaceous, the pores being perfectly empty; the other part is amygdaloidal, the pores or cells being mostly filled up with carbonate of lime, forming white kernels.

Lava.—This term has a somewhat vague signification, having been applied to all melted matter observed to flow in streams from volcanic vents. When this matter consolidates in the open air, the upper part is usually scoriaceous, and the mass becomes more and more stony as we descend, or in proportion as it has consolidated more slowly and under greater pressure. At the bottom, however, of a stream of lava, a small portion of scoriaceous rock very frequently occurs, formed by the first thin sheet of liquid matter, which often precedes the main current, or in consequence of the contact with water in or upon the damp soil.

The more compact lavas are often porphyritic, but even the scoriaceous part sometimes contains imperfect crystals, which have been derived from some older rocks, in which the crystals preexisted, but were not melted, as being more infusible in their nature.

Although melted matter rising in a crater, and even that which enters a rent on the side of a crater, is called lava, yet this term belongs more properly to that which has flowed either in the open air or on the bed of a lake or sea. If the same fluid has not reached the surface, but has been merely injected into fissures below ground, it is called trap.

There is every variety of composition in lavas; some are trachytic, as in the Peak of Teneriffe; a great number are basaltic, as in Vesuvius and Auvergne; others are Andesitic, as those of Chili; some of the most modern in Vesuvius consist of green augite, and many of those of Etna of augite and Labrador-felspar.*

Scoriæ and *Pumice* may next be mentioned as porous rocks, produced by the action of gases on materials melted by volcanic heat. *Scoriæ* are usually of a reddish-brown and black colour, and are the cinders and slags of basaltic or augitic lavas. *Pumice* is a light, spongy, fibrous substance, produced by the action of gases on

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* G. Rose, Ann. des Mines, tom. viii. p. 32.

trachytic and other lavas; the relation, however, of its origin to the composition of lava is not yet well understood. Von Buch says that it never occurs where only Labrador-felspar is present.

Volcanic tuff, Trap tuff.—Small angular fragments of the scoriæ and pumice, above-mentioned, and the dust of the same, produced by volcanic explosions, form the tuffs which abound in all regions of active volcanos, where showers of these materials, together with small pieces of other rocks ejected from the crater, fall down upon the land or into the sea. Here they often become mingled with shells, and are stratified. Such tuffs are sometimes bound together by a calcareous cement, and form a stone susceptible of a beautiful polish. But even when little or no lime is present, there is a great tendency in the materials of ordinary tuffs to cohere together. Besides the peculiarity of their composition, some tuffs, or *volcanic grits,* as they have been termed, differ from ordinary sandstones by the angularity of their grains, and they often pass into *volcanic breccias.*

According to Mr. Scrope, the Italian geologists confine the term *tuff,* or tufa, to felspathose mixtures, and those composed principally of pumice, using the term *peperino* for the basaltic tuffs.* The peperinos thus distinguished are usually brown, and the tuffs grey or white.

We meet occasionally with extremely compact beds of volcanic materials, interstratified with fossiliferous rocks. These may sometimes be tuffs, although their density or compactness is such as to cause them to resemble many of those kinds of trap which are found in ordinary dikes. The chocolate-coloured mud, which was poured for weeks out of the crater of Graham's Island, in the Mediterranean, in 1831, must, when unmixed with other materials, have constituted a stone heavier than granite. Each cubic inch of the impalpable powder which has fallen for days through the atmosphere, during some modern eruptions, has been found to weigh, without being compressed, as much as ordinary trap rocks, and to be often identical with these in mineral composition.

Palagonite-tuff.—The nature of volcanic tuffs must vary according to the mineral composition of the ashes and cinders thrown out of each vent, or from the same vent, at different times. In descriptions of Iceland, we read of Palagonite-tuffs as very common. The name Palagonite was first given by Professor Bunsen to a mineral occurring in the volcanic formations of Palagonia, in Sicily. It is rather a mineral substance than a mineral, as it is always amorphous, and has never been found crystallized. Its composition is variable, but it may be defined as a hydrosilicate of alumina, containing oxide of iron, lime, magnesia, and some alkali. It is of a brown or blackish-brown colour, and its specific density, 2·43. It enters largely into the composition of volcanic tuffs and breccias, and is considered by Bunsen as an altered rock, resulting from the action of steam on volcanic tuffs.

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* Geol. Trans. 2nd series, vol. ii. p. 211.

Agglomerate. — In the neighbourhood of volcanic vents, we frequently observe accumulations of angular fragments of rock, formed during eruptions by the explosive action of steam, which shatters the subjacent stony formations, and hurls them up into the air. They then fall in showers around the cone or crater, or may be spread for some distance over the surrounding country. The fragments consist usually of different varieties of scoriaceous and compact lavas; but other kinds of rock, such as granite or even fossiliferous limestones, may be intermixed; in short, any substance through which the expansive gases have forced their way. The dispersion of such materials may be aided by the wind, as it varies in direction or intensity, and by the slope of the cone down which they roll, or by floods of rain, which often accompany eruptions. But if the power of running water, or of the waves and currents of the sea, be sufficient to carry the fragments to a distance, it can scarcely fail (unless where ice intervenes) to wear off their angles, and the formation then becomes a *conglomerate.* If occasionally globular pieces of scoriæ abound in an agglomerate, they do not owe their rounded form to attrition.

The size of the angular stones in some agglomerates is enormous; for they may be two or three yards in diameter. The mass is often 50 or 100 feet thick, without showing any marks of stratification. The term *volcanic breccia* may be restricted to those tuffs which are made up of small angular pieces of rock.

The slaggy crust of a stream of lava will often, while yet in motion, split up into angular pieces, some of which, after the current has ceased to flow, may be seen to stick up five or six feet above the general surface. Such broken-up crusts resemble closely in structure the agglomerates above described, although the composition of the materials will usually be more homogeneous.

Laterite is a red, jaspery, or brick-like rock composed of silicate of alumina and oxide of iron. The red layers, called "ochre-beds," dividing the lavas of the Giant's Causeway, are laterites. These were found by Delesse to be trap impregnated with the red oxide of iron, and in part reduced to kaolin. When still more decomposed they were found to be clay coloured by red ochre. As two of the lavas of the Giant's Causeway are parted by a bed of lignite, it is not improbable that the layers of laterite seen in the Antrim cliffs resulted from atmospheric decomposition. In Madeira and the Canary Islands streams of lava of subaerial origin are often divided by red bands of laterite, probably ancient soils formed by the decomposition of the surfaces of lava-currents, many of these soils having been coloured red in the atmosphere by oxide of iron, others burnt into a red brick by the overflowing of heated lavas. These red bands are sometimes prismatic, the small prisms being at right angles to the sheets of lava. Red clay or red marl, formed as above stated by the disintegration of lava, scoriæ, or tuff, has often accumulated to a great thickness in the valleys of Madeira, being washed into them by alluvial action; and some of the thick beds of laterite in India may have had a similar origin. In India, however, especially in the Deccan, the term "laterite" seems to have been used too vaguely.

It would be tedious to enumerate all the varieties of trap and lava which have been regarded by different observers as sufficiently abundant to deserve distinct names, especially as each investigator is too apt to exaggerate the importance of local varieties which happen to prevail in districts best known to him. It will be useful, however, to subjoin here, in the form of a glossary, an alphabetical list of the names and synonyms most commonly in use, with brief explanations, to which I have added a table of the analysis of the simple minerals most abundant in the volcanic and hypogene rocks.

Explanation of the Names, Synonyms, and Mineral Composition of the more abundant Volcanic Rocks.

Agglomerate. A coarse breccia, composed of fragments of rock, cast out of volcanic vents, for the most part angular and without any admixture of water-worn stones. "Volcanic conglomerates" may be applied to mixtures in which water-worn stones occur.

Aphanite. *See* Cornean.

Amphibolite, or **Hornblende Rock**, which see.

Amygdaloid. A particular form of volcanic rock; *see* p. 472.

Augite Rock. A rock of the basaltic family, composed of felspar and augite. *See* p. 470.

Augitic-porphyry. Crystals of Labrador-felspar and of augite, in a green or dark grey base. (*Rose, Ann. des Mines*, tom. 8. p. 22. 1835.)

Basalt. An intimate mixture of felspar and augite with magnetic iron, olivine, &c. *See* p. 470.

Basanite. Name given by Alex. Brongniart to a rock, having a base of basalt, with more or less distinct crystals of augite disseminated through it.

Claystone and **Claystone-porphyry.** An earthy and compact stone, usually of a purplish colour, like an indurated clay; passes into hornstone; generally contains scattered crystals of felspar and sometimes of quartz.

Clinkstone. *Syn.* Phonolite, fissile Petrosilex, *see* p. 471.; a greyish-blue rock, having a tendency to divide into slabs; hard, with clean fracture, ringing under the hammer; principally composed of felspar, and, according to Gmelin, of felspar and mesotype. (*Leonhard, Mineralreich*, p. 102.)

Compact Felspar, which has also been called Petrosilex; the rock so called includes the hornstone of some mineralogists, is allied to clinkstone, but is harder, more compact, and translucent. It is a varying rock, of which the chemical composition is not well defined. (*MacCulloch's Classification of Rocks*, p. 481.)

Cornean or **Aphanite.** A compact homogeneous rock without a trace of crystallization, breaking with a smooth surface like some compact basalts; consists of hornblende, quartz, and felspar in intimate combination. It derives its name from the Latin word *cornu*, horn, in allusion to its toughness and compact texture.

Diallage Rock. *Syn.* Euphotide, Gabbro, and some Ophiolites. Compounded of felspar and diallage.

Diorite. A kind of Greenstone, which see. Components, felspar and hornblende in grains. According to *Rose, Ann. des Mines*, tom. 8. p. 4., *diorite* consists of albite and hornblende, but Delesse has shown that the felspar may be

Oligoclase or Labradorite. (*Ann. des Mines*, 1849, tom. 16. p. 323.) Its dark colour is due to disseminated plates of hornblende. *See* above p. 471.

DOLERITE. According to Rose (*ibid.* p. 32.), its composition is black augite and Labrador-felspar; according to Leonhard (*Mineralreich*, &c., p. 77.), augite, Labrador-felspar, and magnetic iron. *See* above, p. 470.

DOMITE. An earthy *trachyte*, found in the Puy de Dome, in Auvergne.

EUPHOTIDE. A mixture of grains of Labrador-felspar and diallage. (*Rose, ibid.* p. 19.) According to some, this rock is defined to be a mixture of augite or hornblende and Saussurite, a mineral allied to jade. (*Allan's Mineralogy*, p. 158.) Haidinger first observed that in this rock hornblende surrounds the crystals of diallage.

FELSPAR-PORPHYRY. *Syn.* Hornstone-porphyry; a base of felspar, with crystals of felspar, and crystals and grains of quartz. *See* also Hornstone.

GABBRO, *see* Diallage rock.

GREENSTONE. *Syn.* A mixture of felspar and hornblende. *See* above, p. 471.

GREYSTONE. (Graustein of Werner.) Lead-grey and greenish rock composed of felspar and augite, the felspar being more than seventy-five per cent. (*Scrope, Journ. of Sci.* No. 42. p. 221.) Greystone lavas are intermediate in composition between basaltic and trachytic lavas.

HORNBLENDE ROCK, or AMPHIBOLITE. This rock, as defined by Leonhard, is composed entirely of hornblende; but such a rock appears to be exceptional, and confined to mineral veins. Any rocks in which hornblende plays a conspicuous part, constituting the "roches amphiboliques" of French writers, may be called hornblende rock. They always contain more or less felspar in their composition, and pass into basalt or greenstone, or aphanite. *See* p. 470.

HORNSTONE-PORPHYRY. A kind of felspar porphyry (*Leonhard, loc. cit.*), with a base of hornstone, a mineral approaching near to flint, differing from compact felspar in being infusible.

HYPERSTHENE ROCK, a mixture of grains of Labrador-felspar and hypersthene (*Rose, Ann. des Mines*, tom. 8. p. 13.), having the structure of syenite or granite; abundant among the traps of Skye. It is extremely tough, grayish, and greenish black. Some geologists consider it a greenstone, in which hypersthene replaces hornblende; and this opinion, says Delesse, is borne out by the fact that hornblende usually occurs in hypersthene rock, often enveloping the crystals of hypersthene. The latter have a pearly or metallic-pearly lustre.

LATERITE. A red, jaspery, brick-like rock, composed of silicate of alumina and oxide of iron, or sometimes consisting of clay coloured with red ochre. *See* above, p. 475.

MELAPHYRE. A variety of black porphyry composed of Labrador-felspar and a small quantity of augite. Its black colour was formerly attributed to disseminated microscopic crystals of augite, but M. Delesse has shown that the paste is discoloured by hydrochloric acid, whereas this acid does not attack the crystals of augite, which are seen to be isolated, and few in number. (*Ann. des Mines*, 4th ser. tom. xii. p. 228.) From *μελας*, *melas*, black.

OBSIDIAN. Vitreous lava like melted glass, nearly allied to pitchstone.

OPHIOLITE. A name given by Al. Brongniart to serpentine.

OPHITE. A name given by Palassou to certain trap rocks of the Pyrenees, very variable in composition, usually composed of Labrador-felspar and hornblende, and sometimes augite, occasionally of a green colour, and passing into serpentine.

PALAGONITE TUFF. An altered volcanic tuff containing the substance termed palagonite. *See* p. 474.

PEARLSTONE. A volcanic rock, having the lustre of mother of pearl; usually having a nodular structure; intimately related to obsidian, but less glassy.

PEPERINO. A form of volcanic tuff, composed of basaltic scoriæ. *See* p. 474.

PETROSILEX. *See* Clinkstone and Compact Felspar.

PHONOLITE. *Syn.* of Clinkstone, which see.

PITCHSTONE, or RETINITE of the French. Vitreous lava, less glassy than obsidian; a blackish green rock resembling glass, having a resinous lustre and appearance of pitch; composition usually of glassy felspar (orthoclase) with a little mica, quartz, and hornblende; in Arran it forms a dike thirty feet wide, cutting through sandstone.

PUMICE. A light, spongy, fibrous form of trachyte. *See* p. 473.

PYROXENIC-PORPHYRY, same as augitic-porphyry, pyroxene being Haüy's name for augite.

SCORIÆ. *Syn.* volcanic cinders; reddish brown or black porous form of lava. *See* p. 473.

SERPENTINE. A greenish rock in which there is much magnesia. Its composition always approaches very near to the mineral called "noble serpentine" (*see* Table of Analyses, p. 479.), which forms veins in this rock. The minerals most commonly found in Serpentine are diallage, garnet, chlorite, oxydulous iron, and chromate of iron. The diallage and garnet occurring in serpentine are richer in magnesia than when they are crystallized in other rocks. (*Delesse, Ann. des Mines*, 1851, tom. xviii. p. 309.) Occurs sometimes, though rarely, in dikes, altering the contiguous strata; is indifferently a member of the trappean or hypogene series. Its absence from recent volcanic products seems to imply that it belongs properly to the metamorphic class; and, even when it is found in dikes cutting through aqueous formations, it may be an altered basalt, which abounded greatly in olivine.

TEPHRINE, synonymous with lava. Name proposed by Alex. Brongniart.

TOADSTONE. A local name in Derbyshire for a kind of wacké, which see.

TRACHYTE. Chiefly composed of glassy felspar, with crystals of glassy felspar. *See* p. 470.

TRAP TUFF. *See* p. 474.

TRASS. A kind of tuff or mud poured out by lake-craters during eruptions; common in the Eifel, in Germany.

TUFF. *Syn.* Trap-tuff, volcanic tuff. *See* p. 474.

VITREOUS LAVA. *See* Pitchstone and Obsidian.

VOLCANIC TUFF. *See* p. 474.

WACKÉ. A soft and earthy variety of trap, having an argillaceous aspect. It resembles indurated clay, and when scratched, exhibits a shining streak.

WHINSTONE. A Scotch provincial term for greenstone and other hard trap rocks.

ANALYSIS OF MINERALS MOST ABUNDANT IN THE VOLCANIC AND HYPOGENE ROCKS.

	Silica.	Alumina.	Magnesia.	Lime.	Potash.	Soda.	Iron Oxide.	Manganese.	Remainder.
Actinolite (Bergman) - - -	64·	- -	22·	- -	- -	- -	3·		
Augite, black, of volcanic rocks (Klaproth).	48·00	5·00	8·75	24·00	- -	- -	10·80	1·00	
Carbonate of lime (Biot) - -	- -	- -	- -	56·33	- -	- -	- -	- -	43·05 C.
Chiastolite (Landgrabe) - -	68·50	30·11	1·13	- -	- -	- -	- -	- -	0·27 W.
Chlorite (Kobell) - - -	31·14	17·14	34·40	- -	- -	- -	3·85	0·53	12·20 W.
——— (Delesse) - - -	31·07	15·47	19·14	0·46	- -	- -	19·99	traces	11·55 W.
——— of St. Gotthardt (Varrentrapp).	25·37	28·79	17·09	- -	- -	- -	28·79	- -	8·96 W.
Diallage of euphotide (Delesse) -	49·30	5·50	17·61	15·43	- -	- -	9·43	0·51	0·85 W. 0·30 Ch.
——— of bronzite from the Tyrol (Köhler).	56·81	2·07	29·68	2·20	- -	- -	8·46	0·62	0·22 W.
Epidote (Vauquelin) - - -	37·	21·	- -	15·	- -	- -	24·	1·5	
Felspar, common (Rose) - -	66·75	17·5	- -	1·25	12·	- -	0·75		
——— (Delesse) -	64·91	19·16	0 65	0·78	11·07	2·49	traces		
——— Albite (Rose) - .	68·84	20·53	- -	a trace	- -	9·12			
——— of a porphyry from the Vosges (Delesse).	71·50	15·50	0·50	1·73	3·16	5·94	traces		
——— Andesine, of syenite from the Vosges (Delesse).	58·91	24·59	0·40	4·01	2·53	7·59	0·99		
——— Labradorite (Klaproth)	55·75	26·5	- -	11·	- -	4·	1·25	- -	0·5 W.
——— of Verde antique (Delesse).	53·20	27·31	1·01	8·02	3·40	3·52	1·03		
——— Oligoclase, of protogine from Mont Blanc (Delesse).	63·25	23·92	0·32	3·23	2·31	6·88	traces		
——— Oligoclase of Arendal (Scheerer).	62·87	22·91	traces	3·61	1·39	8·16	1·89		
Garnet (Klaproth) - - -	35·75	27·25	- -	- -	- -	- -	36·	0·25	
——— (Phillips) - - - -	43·	16·	- -	20·	- -	- -	16·		
Hornblende (Klaproth) - -	42·	12·	2·25	11·	a trace	- -	30·	0·25	
——— (Bonsdorff) - -	45·69	12·18	18·79	13·85	- -	- -	7·32	0·22	1·5 F.
——— of orbicular diorite from Corsica (Delesse).	47·88	8·23	18·40	7·05	0·14	0·65	16·15	traces	1·50 loss.
Hypersthene (Klaproth) - -	54·25	2·25	14·	1·5	- -	- -	24·5	a trace	1· W.
Leucite (Klaproth) - - -	53·75	24·62	- -	- -	21·35				
Malacolite or Sahlite, green (Delesse).	53·42	1·38	14·95	21·72	- -	- -	8·53		
Mesotype (Gehlen) - - -	54·64	19·70	- -	1·61	- -	15·09	- -	- -	9·83 W.
——— (Berzelius) - - -	46·80	26·50	- -	9·87	- -	5·40	- -	- -	12·30 W.
Mica (Klaproth) - - - -	42·5	11·5	9·	- -	10·	-	22·	2·	
——— (Vauquelin) - - -	50·	35·	- -	1·33	- -	- -	7·		
——— black (H. Rose) - - -	40·00	12·67	0·63	- -	5·61	- -	19·03 S.	15·70	1·63 T. 2·00 F.
——— green, of protogine (Delesse)	41·22	13·92	4·70	2·58	6·05	1·40	21·31 S. 5·03 P.	1·09	1·58 F. 0·90 loss
——— reddish, of crystalline limestone (Delesse).	37·54	19·80	30·32	0·70	7·17	1·00	1·61	0·10	0·22 F. 1·51 loss.
——— rose-coloured, of granite (C. Gmelin).	49·06	33·61	0·41	- -	4·19	- -	- -	1·40	3·59 L. 3·28 F. 0·11 P. 4·18 loss.
——— white, of pegmatite (Delesse)	46·23	33·03	2·10	- -	8·87	1·45	3·48 S.	traces	4·12
Olivine (Berzelius) - - -	40·86	- -	47·35	- -	- -	- -	11 72	0·43	
——— (Klaproth) - - -	50·	- -	38·5	0·25	- -	- -	12·		
——— in meteoric stones (Klaproth).	41·0	- -	38·5	- -	- -	- -	18·5		
Serpentine (Hisinger) - - -	43·07	0·25	40·37	0·5	- -	- -	1·17	- -	12·45 W.
——— asbestiform (Delesse)	41·58	0·42	42·61	- -	- -	- -	1·69	- -	13·70 W.
——— common (Delesse) -	40·83	0·92	37·98	1·50	- -	- -	7·39	traces	10·70 W.
Steatite (Delesse) - - -	64·85	- -	28·53	- -	- -	- -	1·40	- -	5·22 W.
——— (Vauquelin) - - -	64·	- -	22·	- -	- -	- -	3·	- -	5· W.
Talc, pure (Delesse) - - -	61·75	- -	31·68	- -	- -	- -	1·70	- -	3·83 W.
——— (Klaproth) - - - .	61·75	- -	30·5	- -	2 75	- -	2·5		
Tourmaline or Schorl, black, of Granite from Devon (Rammelsberg).	37·00	33·09	2·58	0·50	0·65	1·39	9·33 S. 6·19 P.	-	0·12 P. 7·66 B. 2·09 loss. 1·49 F.
——— red, of granite from Moravia (Rammelsberg).	41·16	41·83	0·61	- -	2·17	1·37	- -	97· S.	0·22 Ph. 3·56 B. 0·41 L. 2·70 F. 3·77 loss.
Tourmaline (Gmelin) - - -	35·48	34·75	4·68	- -	0·48	1·75	17·44	1·89	4·02 B.

In the last column of the above Table, the following signs are used: B. Boracic acid, C. Carbonic acid, Ch. Oxide of Chrome, F. Fluoric acid, L. Lithine, P. Phosphoric acid, T. Oxide of Titanium, W. Water. In the 7th column of numbers, P. means Protoxide, and S. Sesquioxide.

CHAPTER XXIX.

VOLCANIC ROCKS—*continued.*

Trap dikes—sometimes project—sometimes leave fissures vacant by decomposition—Branches and veins of trap—Dikes more crystalline in the centre—Strata altered at or near the contact—Obliteration of organic remains—Conversion of chalk into marble—Trap interposed between strata—Columnar and globular structure—Relation of trappean rocks to the products of active volcanos—Form, external structure, and origin of volcanic mountains—Craters and Calderas—Sandwich Islands—Lava flowing underground—Truncation of cones—Javanese calderas—Canary Islands—Structure and origin of the Caldera of Palma—Older and newer volcanic rocks in, unconformable—Aqueous conglomerate in Palma—Hypothesis of upheaval considered—Slope on which stony lavas may form—Extent and nature of aqueous erosion in Palma—Island of St. Paul in the Indian Ocean—Peak of Teneriffe, and ruins of older cone—Madeira—Its volcanic rocks, partly of marine, and partly of subaerial origin—Central axis of eruptions—Varying dip of solid lavas near the axis, and further from it—Leaf-bed, and fossil land-plants—Central valleys of Madeira not craters, or calderas.

HAVING in the last chapter spoken of the composition and mineral characters of volcanic rocks, I shall next describe the manner and position in which they occur in the earth's crust, and their external forms. The leading varieties both of the basaltic and trachytic rocks, as well as of greenstone and the rest, are found sometimes in dikes penetrating stratified and unstratified formations, sometimes in shapeless masses protruding through or overlying them, or in horizontal sheets intercalated between strata.

Volcanic or trap dikes.—Fissures have already been spoken of as occurring in all kinds of rocks, some a few feet, others many yards in width, and often filled up with earth or angular pieces of stone, or with sand and pebbles. Instead of such materials, suppose a quantity of melted stone to be driven or injected into an open rent, and there consolidated, we have then a tabular mass resembling a wall, and called a trap dike. It is not uncommon to find such dikes passing through strata of soft materials, such as tuff, scoriæ, or shale, which, being more perishable than the trap, are often washed away by the sea, rivers, or rain, in which

Fig. 624.

Dike in valley, near Brazen Head, Madeira.
(From a drawing of Capt. Basil Hall, R.N.)

case the dike stands prominently out in the face of precipices, or on the level surface of a country.

In the islands of Arran and Skye, and in other parts of Scotland, where sandstone, conglomerate, and other hard rocks are traversed by dikes of trap, the converse of the above phenomenon is seen. The dike, having decomposed more rapidly than the containing rock, has once more left open the original fissure, often for a distance of many yards inland from the sea-coast, as represented in the annexed view (fig. 625.). In these instances, the greenstone of the dike is usually more tough and hard than the sandstone; but chemical action, and chiefly the oxidation of the iron, has given rise to the more rapid decay.

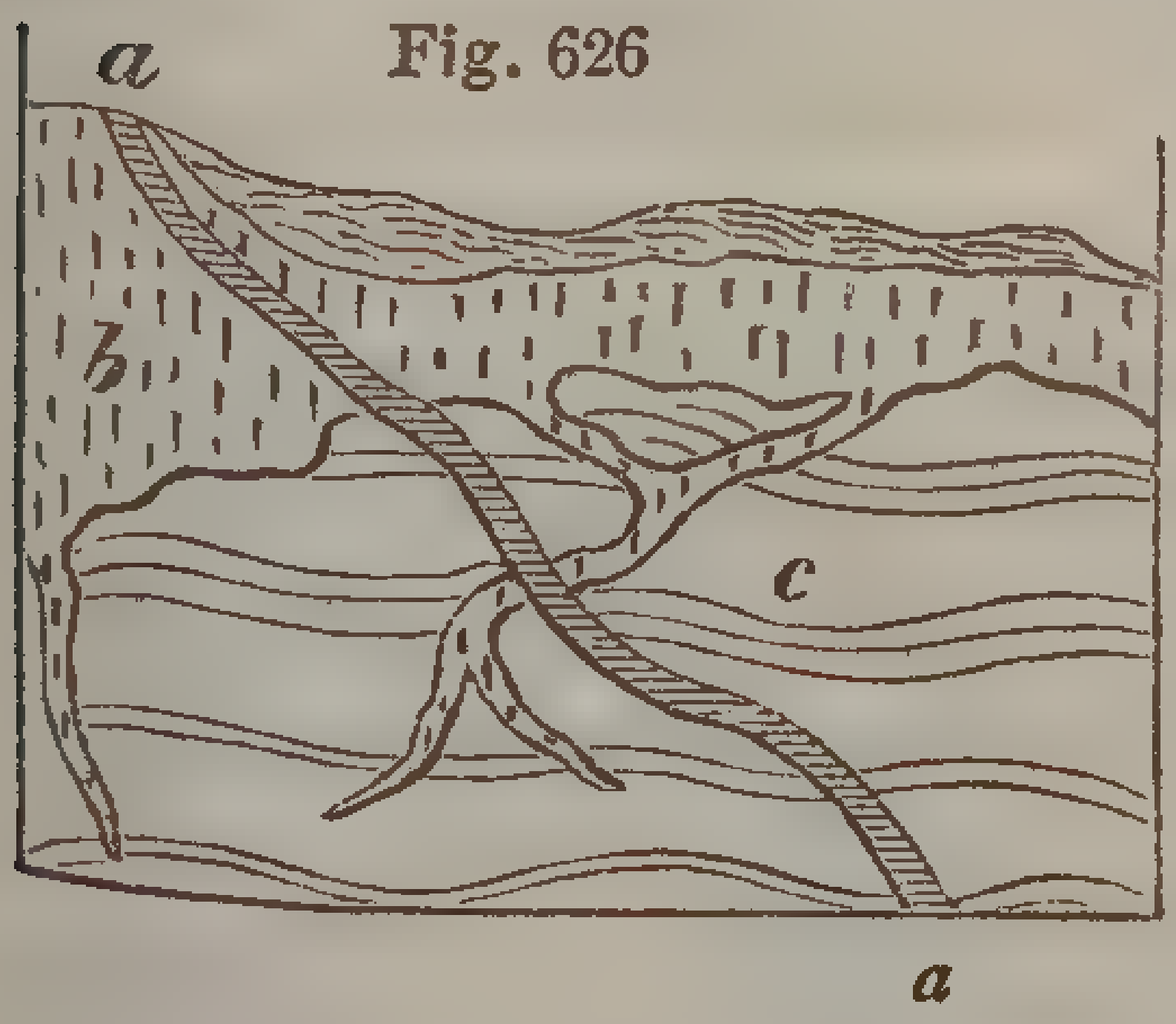
Fig. 625.

Fissures left vacant by decomposed trap. Strathaird, Skye. (MacCulloch.)

There is yet another case, by no means uncommon in Arran and other parts of Scotland, where the strata in contact with the dike, and for a certain distance from it, have been hardened, so as to resist the action of the weather more than the dike itself, or the surrounding rocks. When this happens, two parallel walls of indurated strata are seen protruding above the general level of the country and following the course of the dike.

As fissures sometimes send off branches, or divide into two or more fissures of equal size, so also we find trap dikes bifurcating and ramifying, and sometimes they are so tortuous as to be called veins, though this is more common in granite than in trap. The accompanying sketch (fig. 626.) by Dr. MacCulloch represents part of a sea-cliff in Argyleshire, where an overlying mass of trap, *b*, sends out some veins which terminate downwards. Another trap vein, *a a*, cuts through both the limestone, *c*, and the trap, *b*.

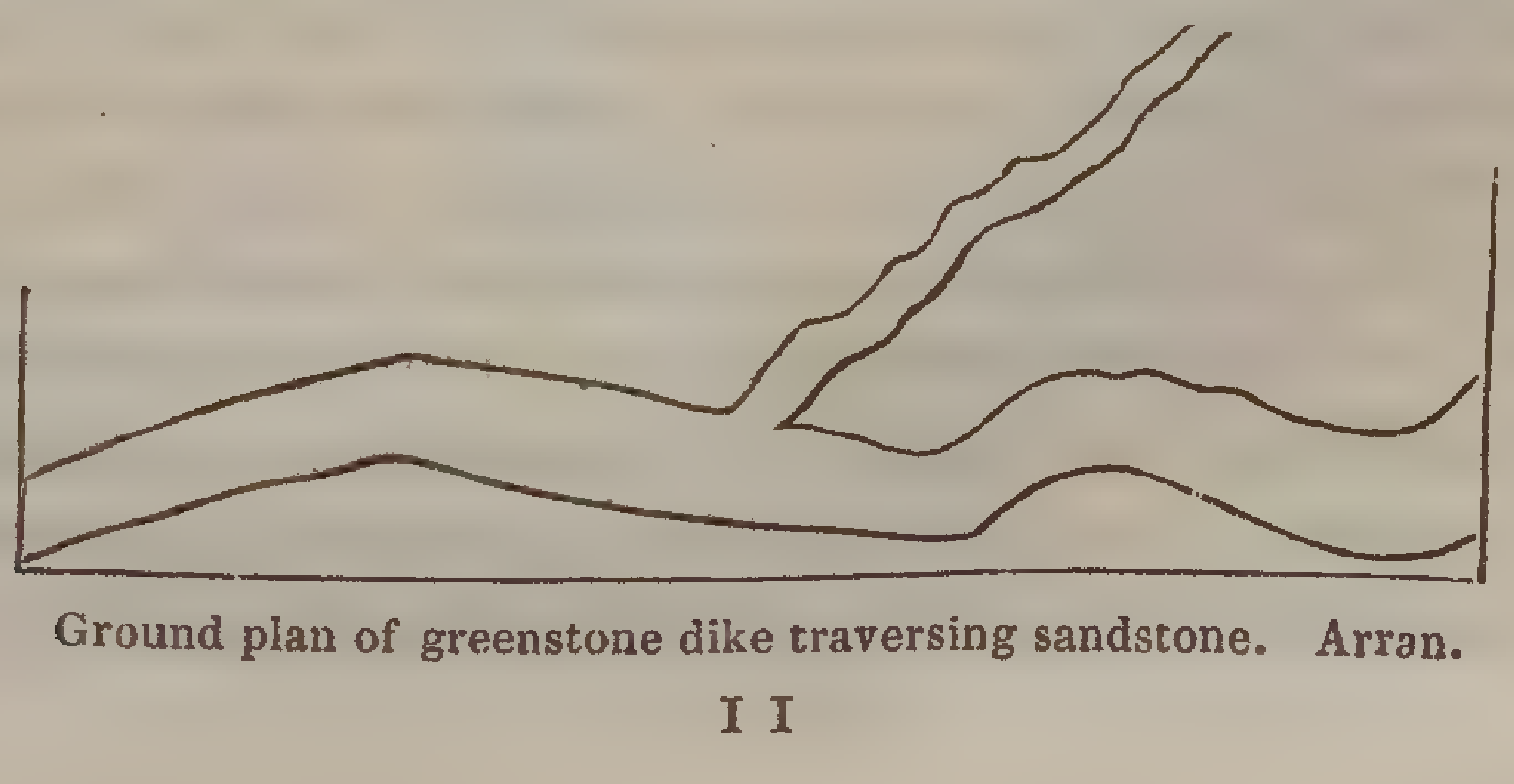
Fig. 626



Trap veins in Airdnamurchan.

In fig. 627., a ground plan is given of a ramifying dike of greenstone, which I observed cutting through

Fig. 627.

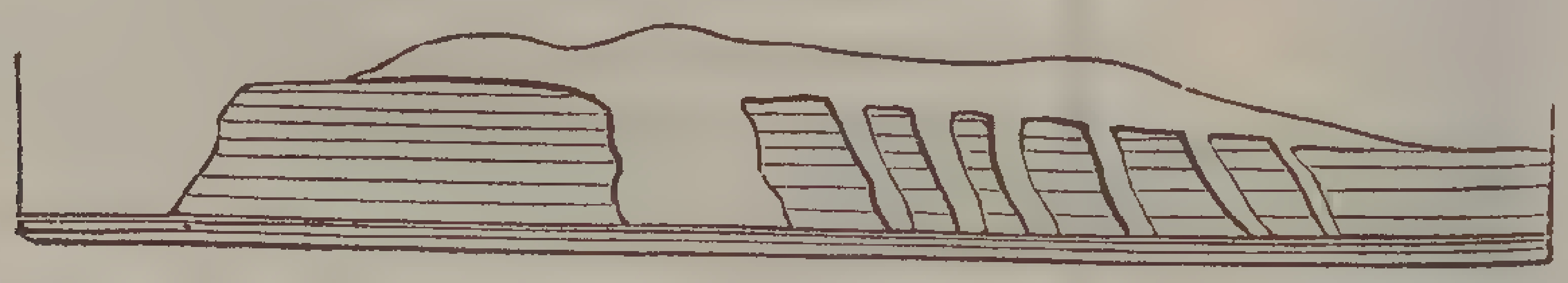


Ground plan of greenstone dike traversing sandstone. Arran.

sandstone on the beach near Kildonan Castle, in Arran. The larger branch varies from 5 to 7 feet in width, which will afford a scale of measurement for the whole.

In the Hebrides and other countries, the same masses of trap which occupy the surface of the country far and wide, concealing the subjacent stratified rocks, are seen also in the sea cliffs, prolonged downwards in veins or dikes, which probably unite with other masses of igneous rock at a greater depth. The largest of the dikes represented in the annexed diagram, and which are seen in part of the coast of Skye, is no less than 100 feet in width.

Fig. 628.



Trap dividing and covering sandstone near Suishnish in Skye. (MacCulloch.)

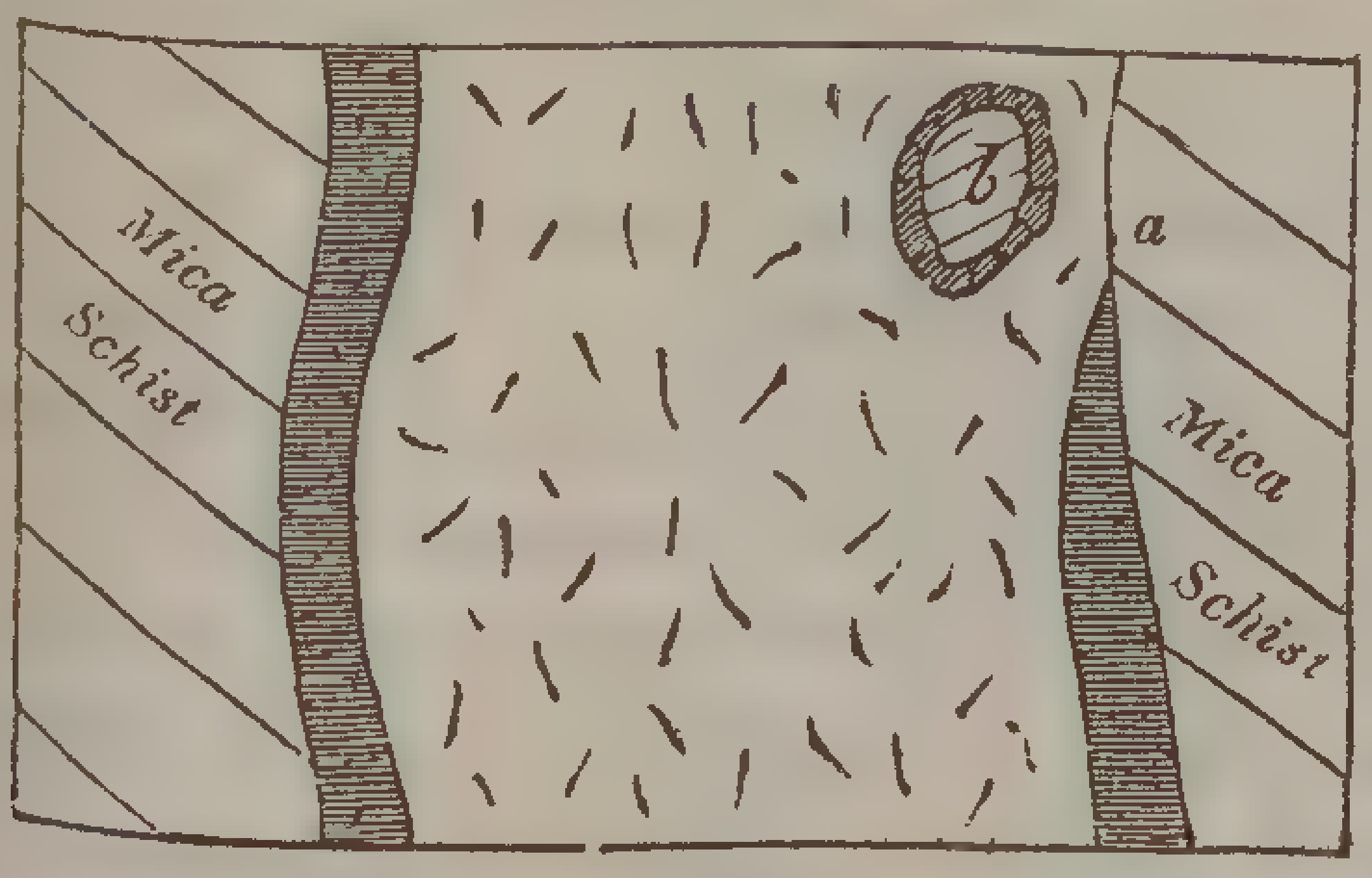
Every variety of trap-rock is sometimes found in dikes, as basalt, greenstone, felspar-porphyry, and trachyte. The amygdaloidal traps also occur, though more rarely, and even tuff and breccia, for the materials of these last may be washed down into open fissures at the bottom of the sea, or during eruptions on the land may be showered into them from the air.

Some dikes of trap may be followed for leagues uninterruptedly in nearly a straight direction, as in the north of England, showing that the fissures which they fill must have been of extraordinary length.

In many cases trap at the edges or sides of a dike is less crystalline or more earthy than in the centre, in consequence of the melted matter having cooled more rapidly by coming in contact with the cold sides of the fissure; whereas, in the centre, where the matter of the dike is kept longer in a fluid or soft state, crystals are slowly formed. But I observed the converse of the above phenomena in Teneriffe, in the neighbourhood of Santa Cruz, where a dike is seen cutting through horizontal beds of scoriæ in the sea-cliff near the Barranco de Bufadero. It is vertical in its main direction, slightly flexuous, and about one foot thick. On each side are walls of compact basalt, but in the centre the rock is highly vesicular for a width of about 4 inches. In this instance, the fissure may have become wider after the lava on each side had consolidated, and the additional melted matter poured into the middle space may have cooled more rapidly than that at the sides.

In the ancient part of Vesuvius, called Somma, a thin band of half-vitreous lava is found at the edge of some dikes. At the junction of greenstone dikes with limestone, a *sahlband*, or selvage, of serpentine is occasionally observed. On the left shore of the fiord of Christiania, in Norway, I examined, in company with Professor Keilhau, a remarkable dike of syenitic greenstone, which is traced through Silurian strata, until at length, in the promontory

Fig. 629.
Syenitic greenstone dike of Næsodden, Christiania.



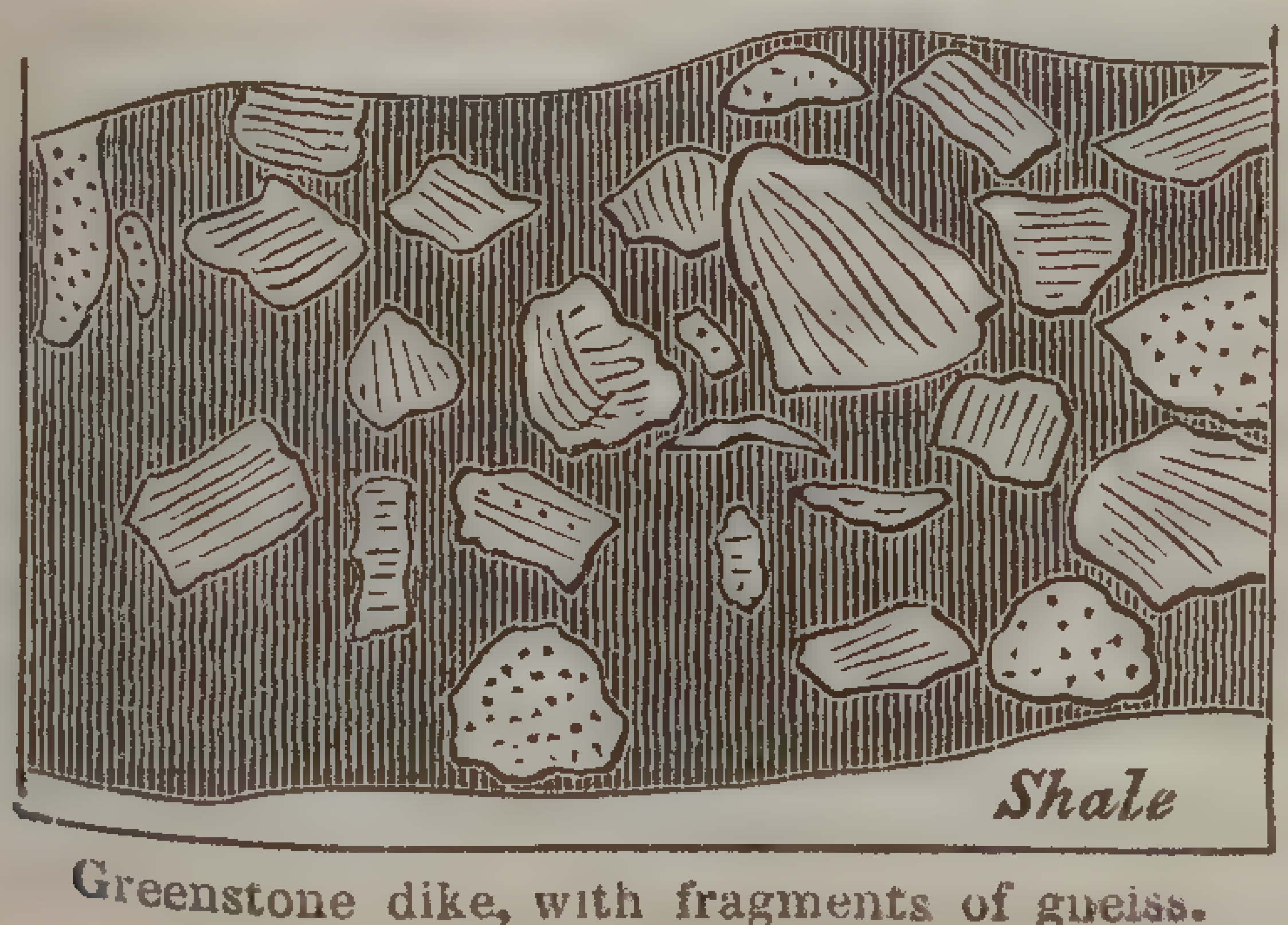
b. imbedded fragment of crystalline schist surrounded by a band of greenstone.

of Næsodden, it enters mica-schist. Fig. 629. represents a ground plan, where the dike appears 8 paces in width. In the middle it is highly crystalline and granitiform, of a purplish colour, and containing a few crystals of mica, and strongly contrasted with the whitish mica-schist, between which and the syenitic rock there is usually on each side a distinct black band, 18 inches wide, of dark greenstone. When first seen, these bands have the appearance of two accompanying dikes; yet they are, in fact, only the different form which the syenitic materials have assumed where near to or in contact with the mica-schist. At one point, *a*, one of the sahlbands terminates for a space; but near this there is a large detached block, *b*, having a gneiss-like structure, consisting of hornblende and felspar, which is included in the midst of the dike. Round this a smaller encircling zone is seen, of dark basalt, or fine-grained greenstone, nearly corresponding to the larger ones which border the dike, but only 1 inch wide.

It seems, therefore, evident that the fragment, *b*, has acted on the matter of the dike, probably by causing it to cool more rapidly, in the same manner as the walls of the fissure have acted on a larger scale. The facts, also, illustrate the facility with which a granitiform syenite may pass into ordinary rocks of the volcanic family.

The fact above alluded to, of a foreign fragment, such as *b*, fig. 629., included in the midst of the trap, as if torn off from some subjacent rock or the walls of a fissure, is by no means uncommon. A fine example is seen in another dike of greenstone, 10 feet wide, in the northern suburbs of Christiania, in Norway, of which the annexed figure is a ground plan. The dike passes through shale, known by its fossils to belong to the Silurian series. In the black base of greenstone are angular and roundish pieces of gneiss, some white, others of a light flesh-colour, some without lamination, like granite, others with laminæ, which, by their various and often opposite directions, show that they have been scattered at random through the matrix. These imbedded pieces of gneiss measure from 1 to about 8 inches in diameter.

Fig. 630.



Greenstone dike, with fragments of gneiss. Sorgenfria, Christiania.

Rocks altered by volcanic dikes.—After these remarks on the form and composition of dikes themselves, I shall describe the alterations which they sometimes produce in the rocks in contact with them. The changes are usually such as the intense heat of melted matter and the entangled gases might be expected to cause.

Plas-Newydd.—A striking example, near Plas-Newydd, in Anglesea, has been described by Professor Henslow.* The dike is 134 feet wide, and consists of a rock which is a compound of felspar and augite (dolerite of some authors). Strata of shale and argillaceous limestone, through which it cuts perpendicularly, are altered to a distance of 30, or even, in some places, to 35 feet from the edge, of the dike. The shale, as it approaches the trap, becomes gradually more compact, and is most indurated where nearest the junction. Here it loses part of its schistose structure, but the separation into parallel layers is still discernible. In several places the shale is converted into hard porcellanous jasper. In the most hardened part of the mass the fossil shells, principally *Producti*, are nearly obliterated; yet even here their impressions may frequently be traced. The argillaceous limestone undergoes analogous mutations, losing its earthy texture as it approaches the dike, and becoming granular and crystalline. But the most extraordinary phenomenon is the appearance in the shale of numerous crystals of analcime and garnet, which are distinctly confined to those portions of the rock affected by the dike.† Some garnets contain as much as 20 per cent. of lime, which they may have derived from the decomposition of the fossil shells or Producti. The same mineral has been observed, under very analogous circumstances, in High Teesdale, by Professor Sedgwick, where it also occurs in shale and limestone, altered by basalt.‡

Antrim.—In several parts of the county of Antrim, in the north of Ireland, chalk with flints is traversed by basaltic dikes. The chalk is there converted into granular marble near the basalt, the change sometimes extending 8 or 10 feet from the wall of the dike, being greatest near the point of contact, and thence gradually decreasing till it becomes evanescent. "The extreme effect," says Dr. Berger, "presents a dark brown crystalline limestone, the crystals running in flakes as large as those of coarse primitive (*metamorphic*) limestone; the next state is saccharine, then fine grained and arenaceous; a compact variety, having a porcellanous aspect and a bluish-grey colour, succeeds: this, towards the outer edge, becomes yellowish-white, and insensibly graduates into the unaltered chalk. The flints in the altered chalk usually assume a grey yellowish colour."§ All traces of organic remains are effaced in that part of the limestone which is most crystalline.

The annexed drawing (fig. 631.) represents three basaltic dikes traversing the chalk, all within the distance of 90 feet. The chalk contiguous to the two outer dikes is converted into a finely granular marble, *m m*, as are the whole of the masses between the outer dikes

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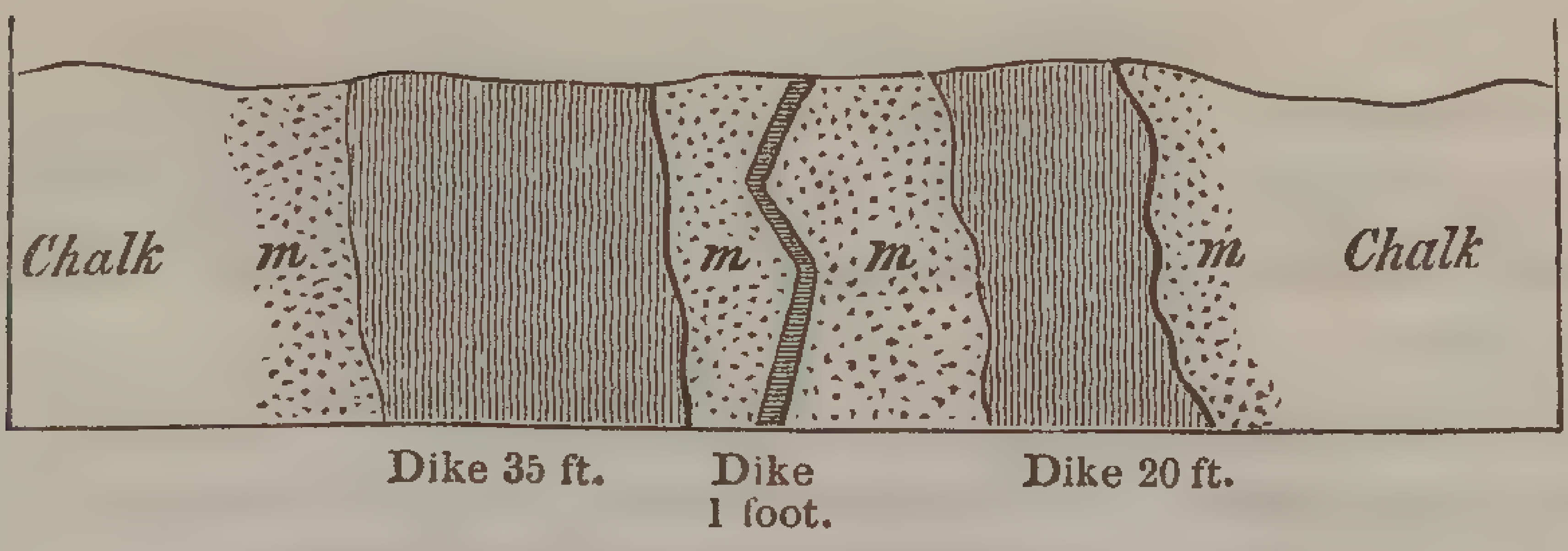
* Cambridge Transactions, vol. i. p. 402.

† Ibid. vol. i. p. 410.

‡ Ibid. vol. ii. p. 175.

§ Dr. Berger, Geol. Trans. 1st series, vol. iii. p. 172.

Fig. 631.



Basaltic dikes in chalk in island of Rathlin, Antrim.
Ground plan, as seen on the beach. (Conybeare and Buckland.*)

and the central one. The entire contrast in the composition and colour of the intrusive and invaded rocks, in these cases, renders the phenomena peculiarly clear and interesting.

Another of the dikes of the north-east of Ireland has converted a mass of red sandstone into hornstone. By another, the shale of the coal-measures has been indurated, assuming the character of flinty slate; and in another place the slate-clay of the lias has been changed into flinty slate, which still retains numerous impressions of ammonites.†

It might have been anticipated that beds of coal would, from their combustible nature, be affected in an extraordinary degree by the contact of melted rock. Accordingly, one of the greenstone dikes of Antrim, on passing through a bed of coal, reduces it to a cinder for the space of 9 feet on each side.

At Cockfield Fell, in the north of England, a similar change is observed. Specimens taken at the distance of about 30 yards from the trap are not distinguishable from ordinary pit-coal; those nearer the dike are like cinders, and have all the character of coke; while those close to it are converted into a substance resembling soot.‡

As examples might be multiplied without end, I shall merely select one or two others, and then conclude. The rock of Stirling Castle is a calcareous sandstone, fractured and forcibly displaced by a mass of greenstone which has evidently invaded the strata in a melted state. The sandstone has been indurated, and has assumed a texture approaching to hornstone near the junction. In Arthur's Seat and Salisbury Craig, near Edinburgh, a sandstone which comes in contact with greenstone is converted into a jaspideous rock.

The secondary sandstones in Skye are converted into solid quartz in several places, where they come in contact with veins or masses of trap; and a bed of quartz, says Dr. MacCulloch, found near a mass of trap, among the coal strata of Fife, was in all probability a stratum of ordinary sandstone, having been subsequently indurated and turned into quartzite by the action of heat.§

But although strata in the neighbourhood of dikes are thus altered

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* Geol. Trans. 1st series, vol. iii. p. 210. and plate 10.

† Ibid. p. 213.; and Playfair, Illust. of Hutt. Theory, s. 253.

‡ Sedgwick, Camb. Trans. vol. ii. p. 37.

§ Syst. of Geol. vol. i. p. 206.

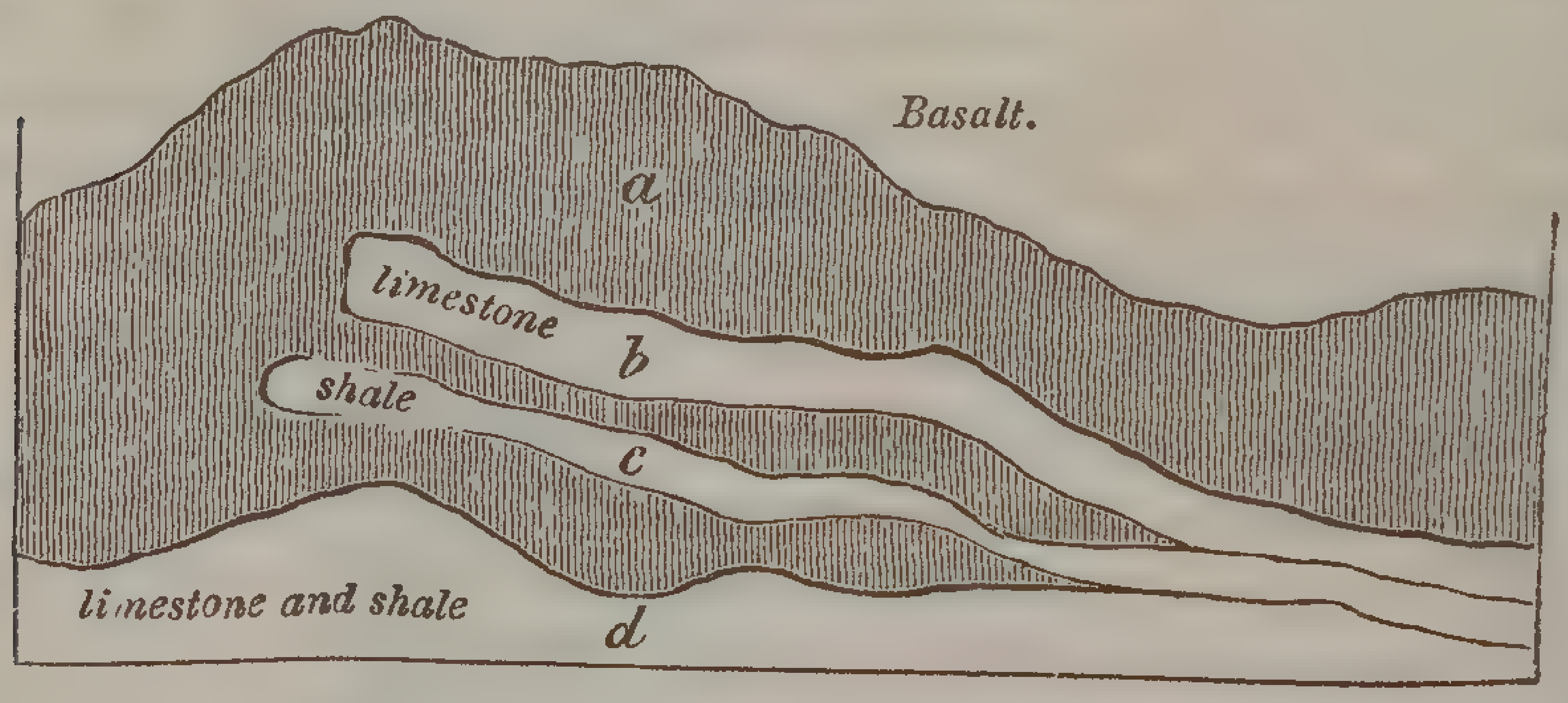
in a variety of cases, shale being turned into flinty slate or jasper, limestone into crystalline marble, sandstone into quartz, coal into coke, and the fossil remains of all such strata wholly and in part obliterated, it is by no means uncommon to meet with the same rocks, even in the same districts, absolutely unchanged in the proximity of volcanic dikes.

This great inequality in the effects of the igneous rocks may often arise from an original difference in their temperature, and in that of the entangled gases, such as is ascertained to prevail in different lavas, or in the same lava near its source and at a distance from it. The power also of the invaded rocks to conduct heat may vary, according to their composition, structure, and the fractures which they may have experienced, and perhaps, also, according to the quantity of water (so capable of being heated) which they contain. It must happen in some cases that the component materials are mixed in such proportions as prepare them readily to enter into chemical union, and form new minerals; while in other cases the mass may be more homogeneous, or the proportions less adapted for such union.

We must also take into consideration, that one fissure may be simply filled with lava, which may begin to cool from the first; whereas in other cases the fissure may give passage to a current of melted matter, which may ascend for days or months, feeding streams which are overflowing the country above, or are ejected in the shape of scoriæ from some crater. If the walls of a rent, moreover, are heated by hot vapour before the lava rises, as we know may happen on the flanks of a volcano, the additional caloric supplied by the dike and its gases will act more powerfully.

Intrusion of trap between strata.—In proof of the mechanical force which the fluid trap has sometimes exerted on the rocks into which it has intruded itself, I may refer to the Whin-Sill, where a mass of basalt, from 60 to 80 feet in height, represented by *a*, fig. 632., is in part wedged in between the rocks of limestone, *b*, and shale, *c*, which have been separated from the great mass of limestone and shale, *d*, with which they were united.

Fig. 632.



Trap interposed between displaced beds of limestone and shale, at White Force, High Teesdale, Durham. (Sedgwick.*)

* Camb. Trans. vol. ii. p. 180.

The shale in this place is indurated; and the limestone, which at a distance from the trap is blue, and contains fossil corals, is here converted into granular marble without fossils.

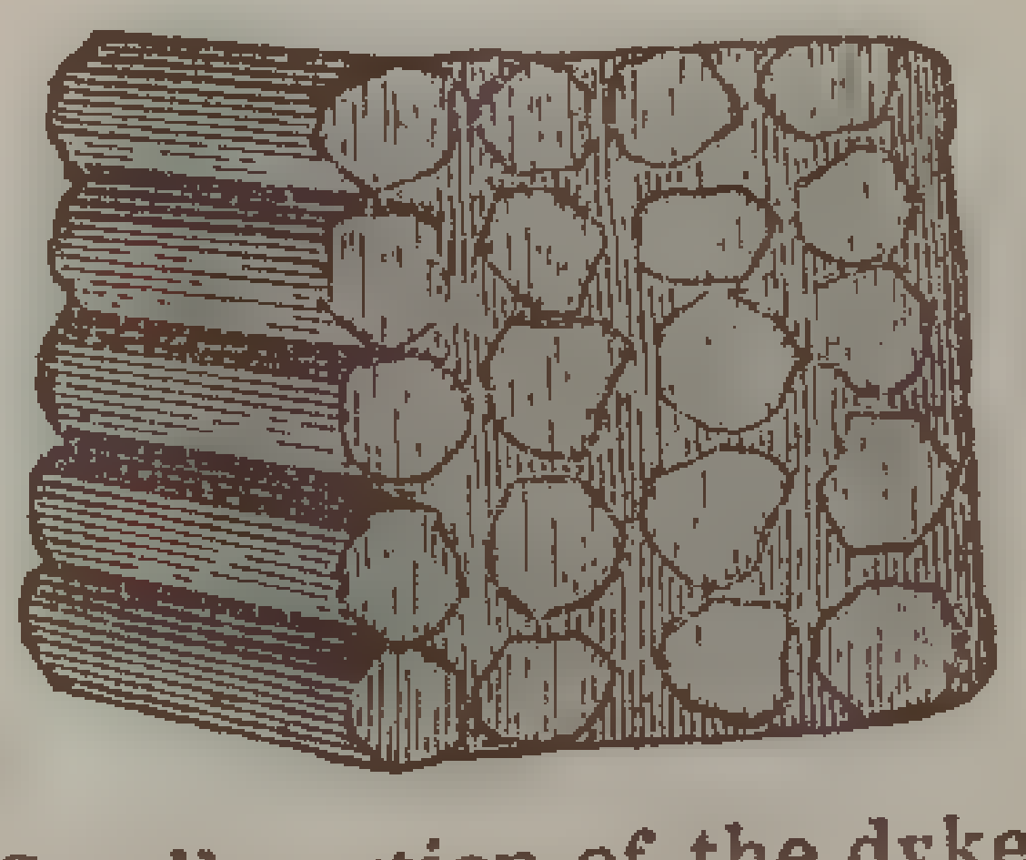
Masses of trap are not unfrequently met with intercalated between strata, and maintaining their parallelism to the planes of stratification throughout large areas. They must in some places have forced their way laterally between the divisions of the strata, a direction in which there would be the least resistance to an advancing fluid, if no vertical rents communicated with the surface, and a powerful hydrostatic pressure were caused by gases propelling the lava upwards.

Columnar and globular structure. — One of the characteristic forms of volcanic rocks, especially of basalt, is the columnar, where large masses are divided into regular prisms, sometimes easily separable, but in other cases adhering firmly together. The columns vary in the number of angles, from three to twelve; but they have most commonly from five to seven sides. They are often divided transversely, at nearly equal distances, like the joints in a vertebral column, as in the Giants' Causeway, in Ireland. They vary exceedingly in respect to length and diameter. Dr. MacCulloch mentions some in Skye which are about 400 feet long; others, in Morven, not exceeding an inch. In regard to diameter, those of Ailsa measure 9 feet, and those of Morven an inch or less.* They are usually straight, but sometimes curved; and examples of both these occur in the island of Staffa. In a horizontal bed or sheet of trap the columns are vertical; in a vertical dike they are horizontal. Among other examples of the last-mentioned phenomenon is the mass of basalt, called the Chimney, in St. Helena (see fig. 633), a pile of hexagonal prisms, 64 feet high, evidently the remainder of a narrow dike, the walls of rock which the dike originally traversed having been re-

Fig. 633.

Volcanic dyke composed of horizontal prisms. St. Helena.

Fig. 634.



Small portion of the dyke in Fig. 633.

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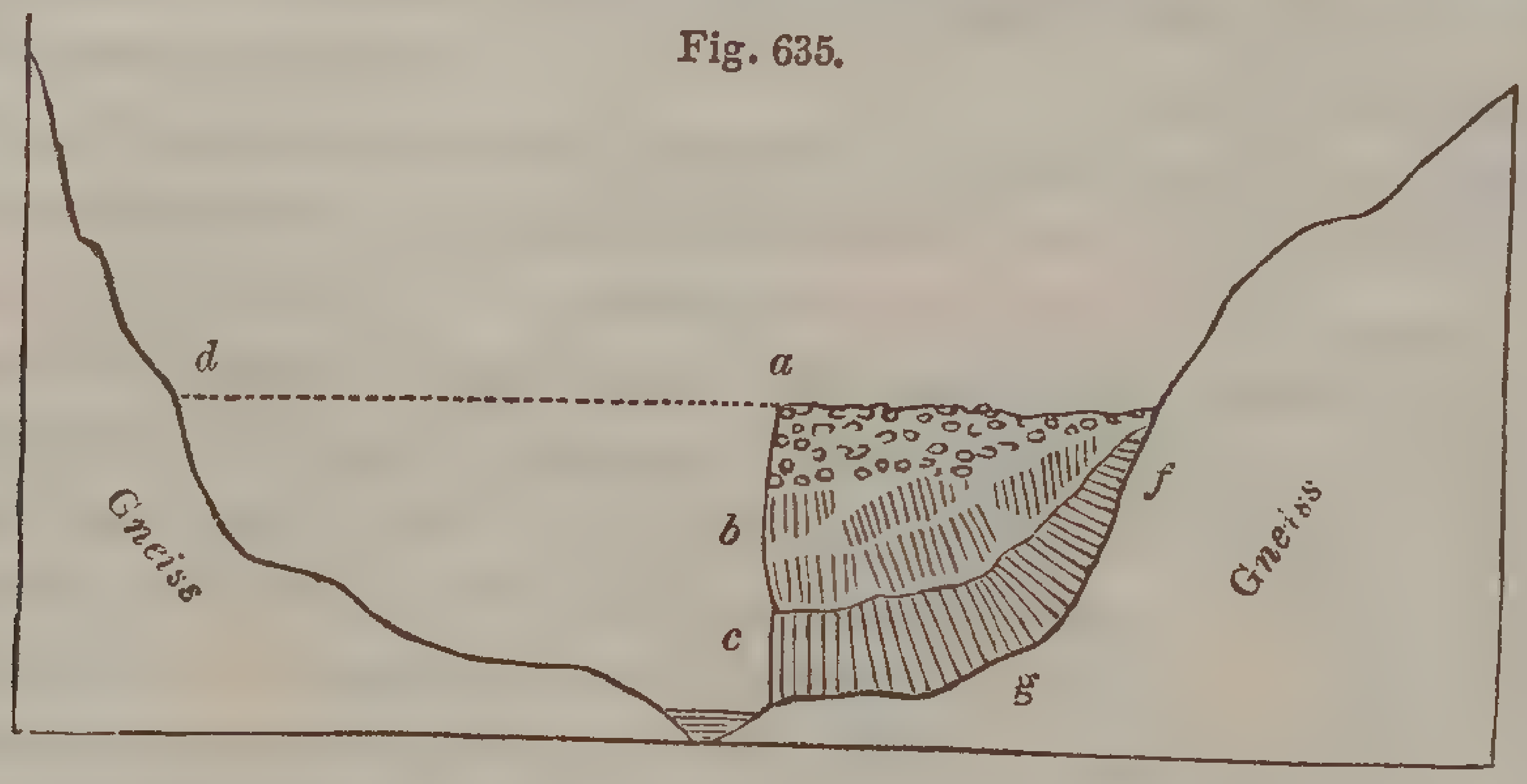
* MacCul. Systᵉ of Geol. vol. ii. p. 137.

moved down to the level of the sea. In fig. 634., a small portion of this dike is represented on a less reduced scale.*

It being assumed that columnar trap has consolidated from a fluid state, the prisms are said to be always at right angles to the *cooling surfaces.* If these surfaces, therefore, instead of being either perpendicular or horizontal, are curved, the columns ought to be inclined at every angle to the horizon; and there is a beautiful exemplification of this phenomenon in one of the valleys of the Vivarais, a mountainous district in the South of France, where, in the midst of a region of gneiss, a geologist encounters unexpectedly several volcanic cones of loose sand and scoriæ. From the crater of one of these cones, called La Coupe d'Ayzac, a stream of lava descends and occupies the bottom of a narrow valley, except at those points where the river Volant, or the torrents which join it, have cut away portions of the solid lava. The accompanying sketch (fig. 635.) represents the remnant of the lava at one of the points where a lateral torrent joins the main valley of the Volant. It is clear that the lava once filled the whole valley up to the dotted line *d a*; but the river has gradually swept away all below that line, while the tributary torrent has laid open a transverse section; by which we perceive, in the first place, that the lava is composed, as usual in this country, of three parts: the uppermost, at *a*, being scoriaceous; the second, *b*, presenting irregular prisms; and the third, *c*, with regular columns, which are vertical on the banks of the Volant, where they rest on a horizontal base of gneiss, but which are inclined at an angle of 45° at *g*, and are horizontal at *f*, their position having been every where determined, according to the law before mentioned, by the concave form of the original valley.

Fig. 635.



Lava of La Coupe d'Ayzac, near Antraigue, in the province of Ardèche.

In the annexed figure (636.) a view is given of some of the inclined and curved columns which present themselves on the sides of the valleys in the hilly region north of Vicenza, in Italy, and at the foot of the higher Alps.† Unlike those of the Vivarais, last mentioned, the basalt of this country was evidently submarine, and the present valleys have since been hollowed out by denudation.

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* Seale's Geognosy of St. Helena, plate 9.

† Fortis. Mém. sur l'Hist. Nat. de l'Italie, tom. i. p. 233. plate 7.

Fig. 636.

Columnar basalt in the Vicentin. (Fortis.)

The columnar structure is by no means peculiar to the trap rocks in which augite abounds; it is also observed in clinkstone, trachyte, and other felspathic rocks of the igneous class, although in these it is rarely exhibited in such regular polygonal forms.

It has been already stated that basaltic columns are often divided by cross joints. Sometimes each segment, instead of an angular, assumes a spheroidal form, so that a pillar is made up of a pile of balls, usually flattened, as in the Cheese-grotto at Bertrich-Baden, in the Eifel, near the Moselle (fig. 637.). The basalt there is part of a small stream of lava, from 30 to 40 feet thick, which has proceeded from one of several volcanic craters, still extant, on the neighbouring heights. The position of the lava bordering the river in this valley might be represented by a section like that already given at fig. 635. if we merely supposed inclined strata of slate and the argillaceous sandstone called greywacké to be substituted for gneiss.

Fig. 637.

Basaltic pillars of the Käsegrotte, Bertrich-Baden, half way between Treves and Coblentz. Height of grotto, from 7 to 8 feet.

In some masses of decomposing greenstone, basalt, and other trap rocks, the globular structure is so conspicuous that the rock has the appearance of a heap of large cannon balls. According to the theory of M. Delesse, the centre of each spheroid has been a centre of crystallization, around which the different minerals of the rock arranged themselves symmetrically during the process of cooling. But it was also, he says, a centre of contraction, produced by the same cooling. The globular form, therefore, of such spheroids is the combined result of crystallization and contraction.*

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* Delesse, ur les Roches Globuleuses, Mém. de la Soc. Géol. de France, 2 ser. tom. iv.

A striking example of this structure occurs in a resinous trachyte or pitchstone-porphyry in one of the Ponza islands, which rise from the Mediterranean, off the coast of Terracina and Gaeta. The globes vary from a few inches to three feet in diameter, and are of an ellipsoidal form (see fig. 638.). The whole rock is in a state of decomposition, "and when the balls," says Mr. Scrope, "have been exposed a short time to the weather, they scale off at a touch into numerous concentric coats, like those of a bulbous root, inclosing a compact nucleus. The laminæ of this nucleus have not been so much loosened by decomposition; but the application of a ruder blow will produce a still further exfoliation."*

Fig. 638.

Globiform pitchstone. Chiaja di Luna, Isle of Ponza. (Scrope.)

A fissile texture is occasionally assumed by clinkstone and other trap rocks, so that they have been used for roofing houses. Sometimes the prismatic and slaty structure is found in the same mass. The causes which give rise to such arrangements are very obscure, but are supposed to be connected with changes of temperature during the cooling of the mass, as will be pointed out in the sequel. (See Chaps. XXXV. and XXXVI.)

Relation of Trappean Rocks to the products of active Volcanos.

When we reflect on the changes above described in the strata near their contact with trap dikes, and consider how complete is the analogy or often identity in composition and structure of the rocks called trappean and the lavas of active volcanos, it seems difficult at first to understand how so much doubt could have prevailed for half a century as to whether trap was of igneous or aqueous origin. To a certain extent, however, there was a real distinction between the trappean formations and those to which the term volcanic was almost exclusively confined. A large portion of the trappean rocks first studied in the north of Germany, and in Norway, France, Scotland, and other countries, were such as had been formed entirely under water, or had been injected into fissures and intruded between strata, and which had never flowed out in the air, or over the bottom of a shallow sea. When these products, therefore, of submarine or subterranean igneous action were contrasted with loose cones of scoriæ, tuff, and lava, or with narrow streams of lava in great part scoriaceous and porous, such as were observed to have proceeded from Vesuvius and Etna, the resemblance seemed remote and equivocal.

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* Scrope, Geol. Trans. 2d series, vol. ii. p. 205.

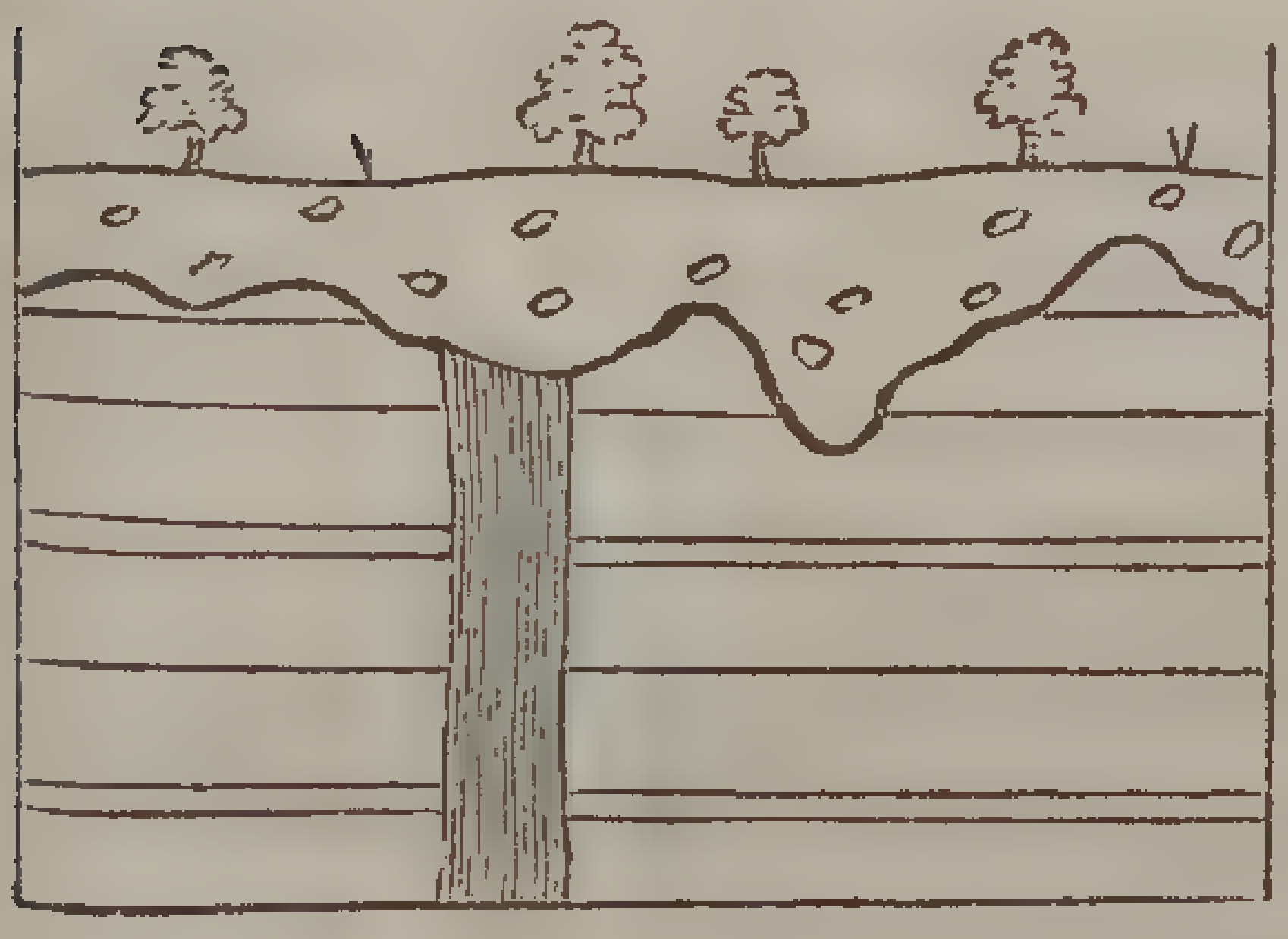
It was, in truth, like comparing the roots of a tree with its leaves and branches, which, although they belong to the same plant, differ in form, texture, colour, mode of growth, and position. The external cone, with its loose ashes and porous lava, may be likened to the light foliage and branches, and the rocks concealed far below, to the roots. But it is not enough to say of the volcano,

> "quantum vertice in auras
> Ætherias, tantum radice in Tartara tendit,"

for its roots do literally reach downwards to Tartarus, or to the regions of subterranean fire; and what is concealed far below is probably always more important in volume and extent than what is visible above ground.

We have already stated how frequently dense masses of strata have been removed by denudation from wide areas (see Chap. VI.); and this fact prepares us to expect a similar destruction of whatever may once have formed the uppermost part of ancient submarine or subaerial volcanos, more especially as those superficial parts are always of the lightest and most perishable materials. The abrupt manner in which dikes of trap usually terminate at the surface (see fig. 639.), and the water-worn pebbles of trap in the alluvium which covers the dike, prove incontestably that whatever was uppermost in these formations has been swept away. It is easy, therefore, to conceive that what is gone in regions of trap may have corresponded to what is now visible in active volcanos.

Fig. 639.



Strata intercepted by a trap dike, and covered with alluvium.

It will be seen in the following chapters, that in the earth's crust there are volcanic tuffs of all ages, containing marine shells, which bear witness to eruptions at many successive geological periods. These tuffs, and the associated trappean rocks, must not be compared to lava and scoriæ which had cooled in the open air. Their counterparts must be sought in the products of modern submarine volcanic eruptions. If it be objected that we have no opportunity of studying these last, it may be answered, that subterranean movements have caused, almost everywhere in regions of active volcanos, great changes in the relative level of land and sea, in times comparatively modern, so as to expose to view the effects of volcanic operations at the bottom of the sea.

Thus, for example, the examination of the igneous rocks of Sicily, especially those of the Val di Noto, has proved that all the more ordinary varieties of European trap have been there produced under the waters of the sea, at a modern period; that is to say, since the Mediterranean has been inhabited by a great proportion of the existing species of testacea.

These igneous rocks of the Val di Noto, and the more ancient trappean rocks of Scotland and other countries, differ from subaerial volcanic formations in being more compact and heavy, and in forming sometimes extensive sheets of matter intercalated between marine strata, and sometimes stratified conglomerates, of which the rounded pebbles are all trap. They differ also in the absence of regular cones and craters, and in the want of conformity of the lava to the lowest levels of existing valleys.

It is highly probable, however, that insular cones did exist in some parts of the Val di Noto: and that they were removed by the waves, in the same manner as the cone of Graham Island, in the Mediterranean, was swept away in 1831, and that of Nyöe, off Iceland, in 1783.* All that would remain in such cases, after the bed of the sea has been upheaved and laid dry, would be dikes and shapeless masses of igneous rock, cutting through sheets of lava which may have spread over the level bottom of the sea, and strata of tuff, formed of materials first scattered far and wide by the winds and waves, and then deposited. Conglomerates also, with pebbles of trap, to which the action of the waves must give rise during the denudation of such volcanic islands, will emerge from the deep whenever the bottom of the sea becomes land. The proportion of volcanic matter which is originally submarine must always be very great, as those volcanic vents which are not entirely beneath the sea are almost all of them in islands, or, if on continents, near the shore.

As to the absence of porosity in the trappean formations, the appearances are in a great degree deceptive, for all amygdaloids are, as already explained, porous rocks, into the cells of which mineral matter such as silex, carbonate of lime, and other ingredients, have been subsequently introduced (see p. 473.); sometimes, perhaps, by secretion during the cooling and consolidation of lavas.

In the Little Cumbray, one of the Western Islands, near Arran, the amygdaloid sometimes contains elongated cavities filled with brown spar; and when the nodules have been washed out, the interior of the cavities is glazed with the vitreous varnish so characteristic of the pores of slaggy lavas. Even in some parts of this rock which are excluded from air and water, the cells are empty, and seem to have always remained in this state, and are therefore undistinguishable from some modern lavas.†

Dr. MacCulloch, after examining with great attention these and the other igneous rocks of Scotland, observes, "that it is a mere dispute about terms, to refuse to the ancient eruptions of trap the name of submarine volcanoes; for they are such in every essential point, although they no longer eject fire and smoke."‡ The same author also considers it not improbable that some of the volcanic

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* See Princ. of Geol., *Index*, "Graham Island," "Nyöe," "Conglomerates, volcanic," &c.

† MacCulloch, West. Islands, vol. ii. p. 487.

‡ Syst. of Geol. vol. ii. p. 114.

rocks of the same country may have been poured out in the open air.*

Although the principal component minerals of subaerial lavas are the same as those of intrusive trap, and both the columnar and globular structure are common to both, there are, nevertheless, some volcanic rocks which never occur in currents of lava, such as greenstone, the more crystalline porphyries, and those traps in which quartz and mica appear as constituent parts. In short, the intrusive trap rocks, forming the intermediate step between lava and the plutonic rocks, depart in their characters from lava in proportion as they approximate to granite.

These views respecting the relations of the volcanic and trap rocks will be better understood when the reader has studied, in the 33rd chapter, what is said of the plutonic formations.

EXTERNAL FORM, STRUCTURE, AND ORIGIN OF VOLCANIC MOUNTAINS.

The origin of volcanic cones with crater-shaped summits has been alluded to in the last chapter (p. 466.), and more fully explained in the "Principles of Geology" (chaps. xxiv. to xxvii.), where Vesuvius, Etna, Santorin, and Barren Island are described. The more ancient portions of those mountains or islands, formed long before the times of history, exhibit the same external features and internal structure which belong to most of the extinct volcanos of still higher antiquity; and these last have evidently been due to a complicated series of operations, varied in kind according to circumstances; as, for example, whether the accumulation took place above or below the level of the sea, whether the lava issued from one or several contiguous vents, and, lastly, whether the rocks reduced to fusion in the subterranean regions happen to have contained more or less silica, potash, soda, lime, iron, and other ingredients.

We are best acquainted with the effects of eruptions above water, or those called subaerial or supramarine; yet the products even of these are arranged in so many ways that their interpretation has given rise to a variety of contradictory opinions, some of which will have to be considered in this chapter.

Craters and Calderas, Sandwich Islands. — We learn from Mr. Dana's valuable work on the geology of the United States' Exploring Expedition, published in 1849, that two of the principal volcanos of the Sandwich Islands, Mounts Loa and Kea in Owyhee, are huge flattened volcanic cones, about 1400 feet high (see fig. 640.), each equalling two and a half Etnas in their dimensions.

From the summits of these lofty though featureless hills, and from vents not far below their summits, successive streams of lava, often 2 miles or more in width, and sometimes 26 miles long, have flowed. They have been poured out one after the other, some of them in recent times, in every direction from the apex of the cone, down

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* Syst. of Geol., vol. ii. p. 114.

Fig. 640.

Mount Loa, in the Sandwich Islands. (Dana.)
a. Crater at the summit. *b.* The lateral crater of Kilauea.
The dotted lines indicate a supposed column of solid rock caused by the lava consolidating after eruptions.

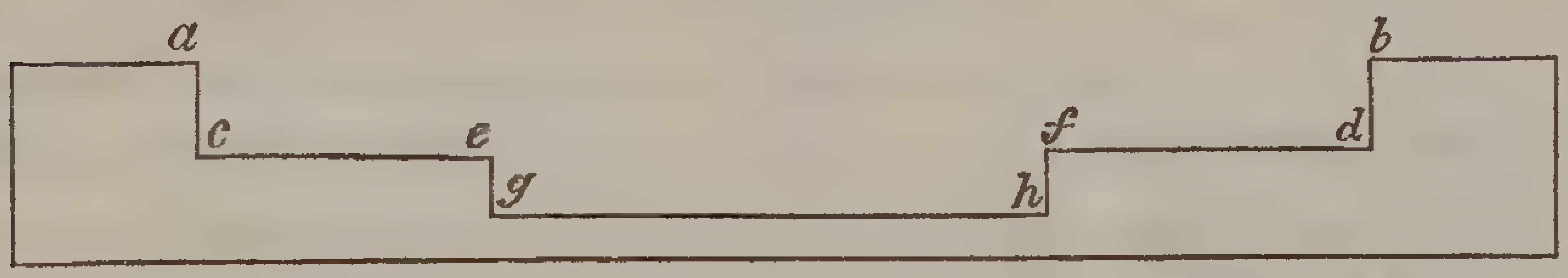
slopes varying on an average from 4 degrees to 8 degrees; but in some places considerably steeper. Sometimes deep rents are formed on the sides of these conical mountains, which are afterwards filled from above by streams of lava passing over them, the liquid matter in such cases consolidating in the fissures and forming *dikes.*

The lateral crater of Kilauea, *b*, fig. 640., is 3970 feet above the level of the sea, or about the same height as Vesuvius. It is an immense chasm, 1000 feet deep, and its outer circuit no less than from two to three miles in diameter. Lava is usually seen to boil up at the bottom in a lake, the level of which alters continually, for the liquid rises and falls several hundred feet according to the active or quiescent state of the volcano. But instead of overflowing the rim of the crater, as commonly happens in other vents, the column of melted rock, when its pressure becomes excessive, forces a passage through some subterranean galleries or rents leading towards the sea. Mr. Coan, an American missionary, has described an eruption which took place in June 1840, when the lava which had risen high in the great chasm began to escape from it. Its direction was first recognised by the emission of a vivid light from the bottom of an ancient wooded crater, called Arare, 400 feet deep and 6 miles to the eastward of Kilauea. The connection of this light with the discharge or tapping of the great reservoir was proved by a change in the level of the lava in Kilauea, which sank gradually for three weeks, or until the eruption ceased, when the lake stood 400 feet lower than at the commencement of the outbreak. The passage, therefore, of the fluid matter from Kilauea to Arare was underground, and it is supposed by Mr. Coan to have been at its first outflow 1000 feet deep below the surface. The next indication of the subterranean progress of the same lava was observed a mile or two from Arare, where the fiery flood broke out and spread itself superficially over 50 acres of land, and then again found its way underground for several miles farther towards the sea, to reappear at the bottom of a second ancient and wooded crater, which it partly filled up. The course of the fluid then became again invisible for several miles, until it broke out for the last time at a point ascertained by Captain Wilkes to be 1244 feet above the sea, and 27 miles distant from Kilauea. From thence it poured along for 12 miles in the open air, and then leapt over a cliff 50 feet high, and ran for three weeks into the sea. Its termination was at a place about 40 miles distant from Kilauea. The crust of the earth overlying the subterranean course of the lava was often traversed by innumerable fissures, which emitted steam, and in some places the incumbent rocks were uplifted 20 or 30 feet.

Thus in the same volcano examples are afforded of the overflowing of lava from the summit of a cone 2½ miles high, and of the underflowing of melted matter. Whether this last has formed sheets intercalated between the stratified products of previous eruptions, or whether it has penetrated through oblique or vertical fissures, cannot be determined. In one instance, however, for a certain space, it is said to have spread laterally, uplifting the incumbent soil.

The annexed section of the crater of Kilauea, as given by Mr. Dana, follows the line of its shorter diameter, *a*, *b*, which is about 7500 feet long. The boundary cliffs, *a*, *c* and *b*, *d*, are for the most part quite vertical and 650 feet high. They are composed of compact rock in layers, not divided by scoriæ, some a few inches, others 30 feet in thickness, and nearly horizontal. Below this, we come to what is called the "black ledge," *c*, *e* and *f*, *d*, composed of similar stratified materials. This ledge is 342 feet in height above the lake of lava, *g*, *h*, which it encircles. The chasm, *a*, *b*, and its walls have probably been due to a former sinking down of the incumbent rocks, undermined for a space by the fusion of their foundations. The lower ledge, *c*, *e* and *f*, *d*, may consist in part of the mass which sank vertically, but part of it at least must be made up of layers of lava, which have been seen to pour one after the other over the "black ledge." If at any future period the heated fluid, ascending from the volcanic focus to the bottom of the great chasm, should augment in volume, and, before it can obtain relief, should spread itself subterraneously, it may melt still farther the subjacent masses, and, causing a failure of support, may enlarge still more the limits of the amphitheatre of Kilauea. There are distinct signs of subsidences, from 100 to 200 feet perpendicular, which have occurred in the neighbourhood of Kilauea at various points, and they are each bounded by vertical walls. If all of them were united, they would constitute a sunken area equal to eight square miles, or twice the extent of Kilauea itself. Similar accidents are also likely to occur near the summit of a dome like Mount Loa, for the hydrostatic pressure of the lava, after it has risen to the edge or lip of the highest crater, *a*, fig. 640., must be great and must create a tendency to lateral fissuring, in which case lava will be injected into every opening, and may begin to undermine. If, then, some of the melted matter be drawn off by escaping at a lower level, where

Fig. 641.



Section of the crater of Kilauea in the Sandwich Islands. (Dana.)
a, *b*. External boundaries of the chasm in the line of its shortest diameter.
c, *e*, *f*, *d*. Black ledge. *g*, *h*. Lake of lava.

the pressure would be still greater, the whole top of the mountain, or a large part of it, might fall in.

Instances of such truncations, however caused, have occurred in Java and in the Andes within the times of history, and to such events we may perhaps refer a very common feature in the configuration of volcanic mountains, — namely, that the present active cone of eruption is surrounded by the ruins of a larger and older cone, usually presenting a crescent-shaped precipice towards the newer cone. In volcanos long since extinct, the erosive power of running water, or, in certain cases, of the sea, may have greatly modified the shape of the "atrium," or space between the older and newer cone, and the cavity may thereby be prolonged downwards, and end in a ravine. In such cases it may be impossible to determine how much of the missing rocks has been removed by explosion at the time when the original crater was active, or how much by subsequent engulphment and denudation.

Java. — One of the latest contributions to our knowledge of volcanos will be found in Dr. Junghuhn's work on Java, where forty-six conical eminences of volcanic origin, varying in elevation from 4000 to nearly 12,000 feet above the sea, constitute the highest peaks of a mountain range, running through the island from east to west. All of them, with one exception, did this indefatigable traveller survey and map. In none of them could he discover any marine remains, whether adhering to their flanks or entering into their internal structure, although strata of marine origin are met with nearer the sea at lower levels. Dr. Junghuhn ascribes the origin of each volcano to a succession of subaerial eruptions from one or more central vents, whence scoriæ, pumice, and fragments of rock were thrown out, and whence have flowed streams of trachytic or basaltic lava. Such overflowings have been witnessed in modern times from the highest summits of several of the peaks. The external slope of each cone is generally greatest near its apex, where the volcanic strata have also the steepest dip, sometimes attaining angles of 20, 30, and 35 degrees, but becoming less and less inclined as they recede from the summit, until, near their base, the dip is reduced to 10 and often 4 or 5 degrees.* The interference of the lavas of adjoining volcanos sometimes produces elevated platforms, or "saddles," in which the layers of rock may be very slightly inclined. At the top of many of the loftiest mountains the active cone and crater are of small size, and surrounded by a plain of ashes and sand, this plain being encircled in its turn by what Dr. Junghuhn calls "the old crater-wall," which is often 1000 feet and more in vertical height. There is sometimes a terrace of intermediate height (as in the mountain called Tengger), comparable to the "black ledge" of Kilauea (fig. 641). Most of the spaces thus bounded by semicircular or more than semicircular ranges of cliffs are vastly superior in dimensions to

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* Java, deszelfs gedaante, bekleeding en invendige structuur, door F. Junghuhn. (German translation of 2d edit. by Hasskarl, Leipzig, 1852.)

the area of any known crater or hollow which has been observed in any part of the world to be occupied by a lake of liquid lava. As the Spaniards have given to such large cavities the name of Caldera (or cauldron), it may be useful to use this term in a technical sense, whatever views we may entertain as to their origin. Many of them in Java are no less than four geographical miles in diameter, and they are attributed by Junghuhn to the truncation by explosion and subsidence of ancient cones of eruption. Unfortunately, although several lofty cones have lost a portion of their height within the memory of man, neither the inhabitants of Java nor their Dutch rulers have transmitted to us any reliable accounts of the order of events which occurred.*

Dr. Junghuhn believes that Papandayang lost some portion of its summit in 1772; but affirms that most of the towns on its sides said to have been engulphed were in reality overflowed by lava.

From the highest parts of many Javanese *calderas* rivers flow, which in the course of ages have cut out deep valleys in the mountain's side. As a general rule, the outer slopes of each cone are furrowed by straight and narrow ravines from 200 to 600 feet deep, radiating in all directions from the top, and increasing in number as we descend to lower zones. The ridges or "ribs," intervening between these furrows, are very conspicuous, and compared to the spokes of an umbrella. In a mountain above 10,000 feet high, no furrows or intervening ribs are met with in the upper 300 or 400 feet. At the height of 10,000 feet there may be no more than 10 in number, whereas 500 feet lower 32 of them may be counted. They are all ascribed to the action of running water; and if they ever cut through the rim of a caldera, it is only because the cone has been truncated so low down as to cause the summit to intersect a middle region, where the torrents once exerted sufficient power to cause a series of such indentations. It appears from such facts, that, if a cone escapes destruction by explosion or engulphment, it may remain uninjured in its upper portion, while there is time for the excavation of deep ravines by lateral torrents.

It is remarked by Dr. Junghuhn, as also by Mr. Dana in regard to the Pacific Islands, that volcanic mountains, however large and however much exposed to heavy falls of rain, support no rivers so long as they are in the process of growth, or while the highest crater emits from time to time showers of scoriæ and floods of lava. Such ejectamenta and such currents of melted rock fill up each superficial inequality or depression where water might otherwise collect, and are moreover so porous that no rill of water, however small, can be generated. But where the subterranean fires have been long since spent, or are nearly exhausted, and where the superficial scoriæ and lavas decompose and become covered with clayey soils, the corrosive action of water begins to operate with a prodigious force, proportionate to the steepness of the declivities and the in-

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* See Principles of Geol., 9th edit. p. 493.

coherent nature of the sand and ashes. Even the more solid lavas are occasionally cavernous, and almost always alternate with scoriæ and perishable tuffs, so as to be readily undermined, and most of them are speedily reduced to fragments of a transportable size because they are divided by vertical joints or split into columns.

Canary Islands — Palma. — I have enlarged so fully in the "Principles of Geology" on the different views entertained by eminent authorities respecting the origin of volcanic cones, and the laws governing the flow of lava, and its consolidation, that, in order not to repeat here what I have elsewhere published, I shall confine myself in the remainder of this chapter to the description of facts observed by me during a recent exploration of Madeira and some of the Canary Islands. In these excursions, made in the winter of 1853-4, I was accompanied by an active fellow-labourer, Mr. Hartung, of Konigsberg. We visited among other places the beautiful island of Palma, a spot rendered classical by the description given of it in 1825 by the late Leopold Von Buch, who regarded it as a type of what he called a "crater of elevation."*

Fig. 642.

Map of Palma, from Survey of Capt. Vidal, R.N.

Palma is 16 geographical miles west of Teneriffe. Seen from the channel which divides the two islands, Palma appears to consist of two principal mountain masses, the depression between them being at *a* (map, fig. 642.), or at the pass of Tacanda, which is about 4600 feet above the sea-level. The most northern of these masses makes, notwithstanding certain irregularities hereafter to be mentioned, a considerable approach in general form to a great truncated cone, having in the centre a huge and deep cavity called by the inhabitants "La Caldera." This cavity (*b*, *c*, *d*, *e*, fig. 642.) is from 3 to 4 geographical miles in diameter, and the range of precipices surrounding it vary from about 1500 to 2500 feet in vertical height. From their base a steep slope, clothed by a splendid forest of pines, descends for a thousand and sometimes two thousand feet lower, the centre of the Caldera being about 2000 feet above the sea. The northern half of the encircling ridge is more than 7000 English feet above the sea in its highest peaks, and is annually white with snow during the winter months.

Externally the flanks of this truncated cone incline outwards in every direction, the slopes being steepest near the crest, and lessening

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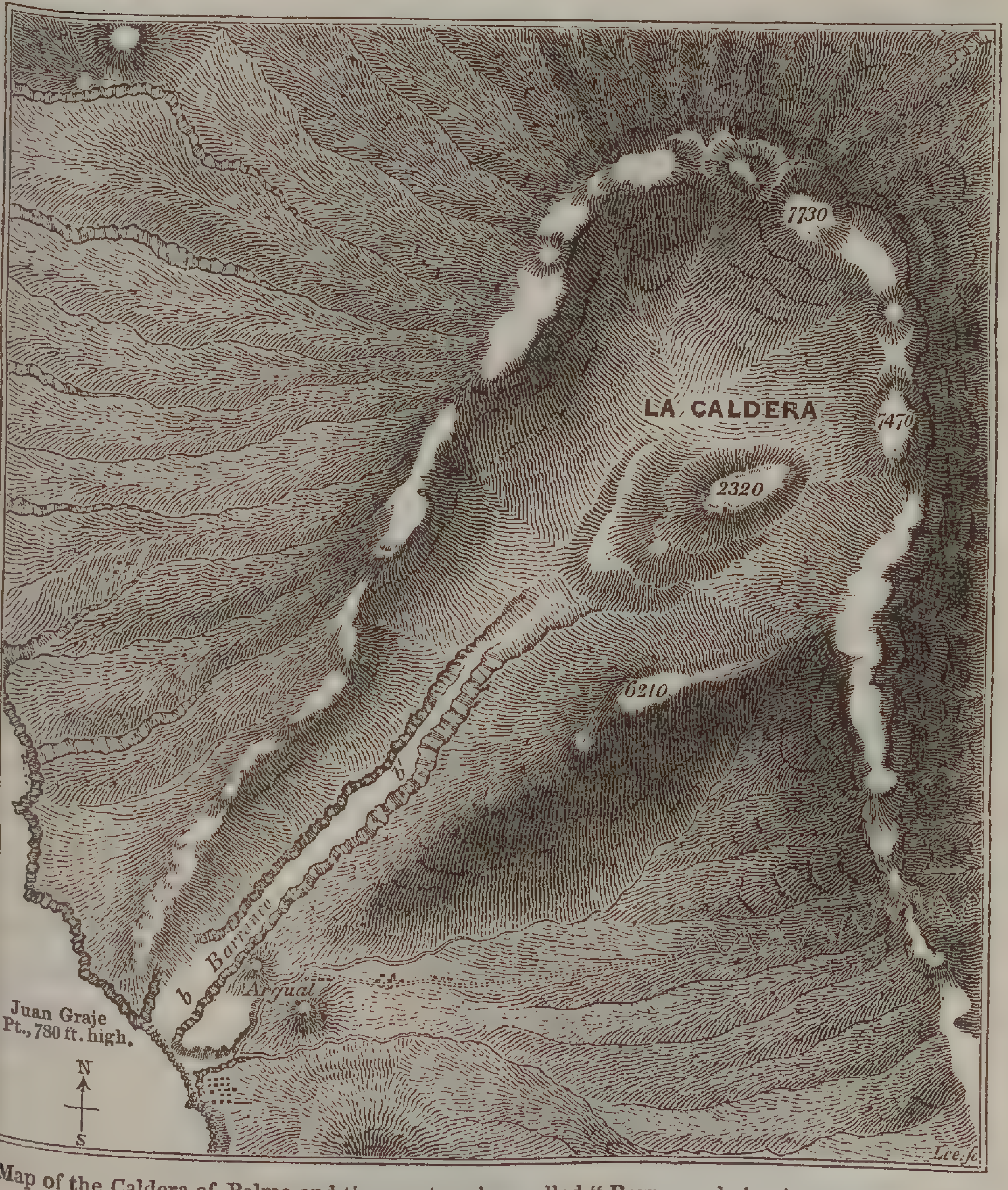
* Erhebung's Crater.

as they approach the lower country. A great number of ravines commence on the flanks of the mountain, a short distance below the summit, shallow at first, but getting deeper as they descend, and becoming at the same time more numerous, as in the cones of Java before mentioned.

So unbroken is the precipitous boundary-wall of the Caldera, except at its south-eastern end, where the torrent which drains it through a deep gorge (*b*, *b*′, fig. 643.) issues, that there is not even a footpath by which one can descend into it save at one place called the Cumbrecito (*e*, map, fig. 642. p. 498.). This Cumbrecito is a narrow *col* or watershed at the height of about 2000 feet above the bottom of the Caldera, and 4000 above the sea, and situated at the precise limit of two geological formations presently to be mentioned. This *col* also occurs at the level where, in other parts of the Caldera, the vertical precipices join the talus-like, rocky slope, covered with pines. The other or principal entrance by which the Caldera is

Fig. 643.



Map of the Caldera of Palma and the great ravine, called "Barranco de las Angustias." From the Survey of Capt. Vidal, R. N., 1837. Scale, two geographical miles to an inch.

drained is the great ravine or *barranco*, as it is called (see *b*, *b′*, fig. 643.), which extends from the south-western extremity of the Caldera to the sea, a distance of 4½ geographical miles, in which space the water of the torrent falls about 1500 feet.

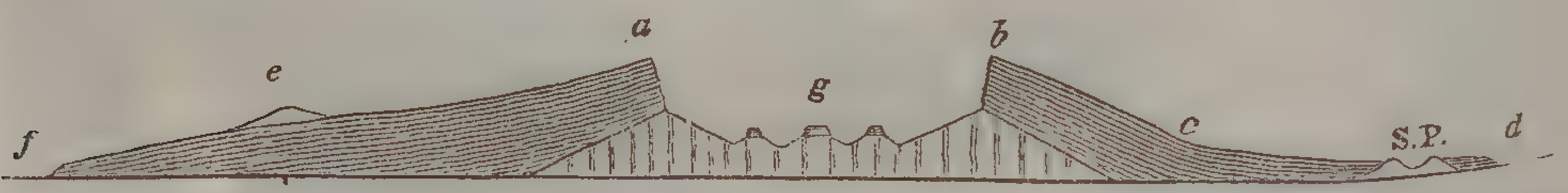
Fig. 644.

View of the Isle of Palma, and of the entrance into the central cavity or Caldera. From Von Buch's "Canary Islands."

This sketch was taken by Von Buch from a point at sea not visited by us, but we saw enough to convince us that several lateral cones ought to have been introduced on the great slope to the left, besides numerous deep furrows radiating from near the summit to the sea (see the map, fig. 643.). The sea does not enter the great Barranco, as might be inferred from this sketch.

The annexed section (fig. 645.) passes through the island from Santa Cruz de Palma to Briera Point, or from south-east to north-west (see map, p. 498.). It has been drawn up on a true scale of heights and horizontal distances from the observations of Mr. Hartung and my own.

Fig. 645.



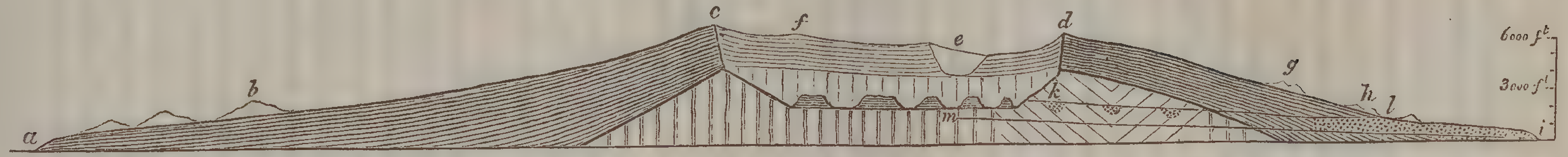
Section of the Island of Palma, from Point Briera, on the north-west, to Santa Cruz de Palma, on the south-east. See map, fig. 642., p. 498.

a, *b*. The Caldera (height of *a*, 6000 feet).
c. Commencement of steeper dip.
d. Santa Cruz de Palma or Tedote.
e. Lateral cone, 3940 feet above the sea (Vidal's Map).
f. Briera Point.
g. One of several outliers of the upper formation in centre of Caldera.
S. P. Half-buried cone and crater of San Pedro.

The lavas are seen to be slightly inclined near the sea at Santa Cruz, where we observed them flowing round the cone of San Pedro, which they have more than half buried without entering the crater. On starting from the same part of the sea-coast, and ascending the deep Barranco de la Madera, we saw just below *c* the basaltic lavas dipping at an angle of 5 degrees, there being no dikes in that region. Farther up, where the dikes were still scarce, the dip of the beds increases to 10 and 15 degrees, and they become still steeper as they approach the Caldera at *b*, where dikes abound.

Fig. 646.

SECTION OF THE ISLAND OF PALMA, FROM NORTH-EAST TO SOUTH-WEST.



This section passes through the Caldera and the Barranco de las Angustias, and is drawn up on a true scale of height and horizontal distance, from the observations of C. Lyell and G. Hartung. 1854. (See Map, p. 498.)

a. Barlovento Point, see map, fig. 642., p. 498.
b. One of several cones, S.S.E. from Barlovento Point.
c. Pico de la Cruz, 7730 feet high, forming part of the northern boundary of the Caldera.
c, d. The Caldera.
d. The summit of the mountain called Alejanado, 6210 feet high, forming the southern wall of the Caldera.
e. The Cumbrecito, or higher opening into the Caldera.
f. Pico de Cedro, 7470 feet high; the highest point on the eastern margin of the Caldera.
g. Lateral cone on the flanks of Alejanado.
h. Cone of Argual.
i. Cliff of Tazacorte.
k, l. Old inclined water-line, marked by upper limit of gravel or conglomerate.
m, i. Level of the river or torrent of the Barranco de las Angustias.

The stronger lines in this diagram express that part which alone falls into the line of section; the fainter lines that portion of the eastern circuit of the Caldera which is in perspective, and could be seen by a spectator standing on the west side.

The section (fig. 646.) is at right angles to the preceding, and cuts through the cone in the direction of the great Barranco, or from north-east to south-west.

The lowest of the two slanting lines, *m*, *i*, descending from the Caldera to the sea along the bottom of the Barranco, represents the present bed of the torrent; the upper line, *k*, *l*, the height at which beds of gravel, elevated high above the present river-channel, are visible in detached patches, shown by dotted spaces at *k*, and to the south-west of it, on the same slope. These, and the continuous stratified gravel and conglomerate lower down at *l* and *i*, are newer than all the volcanic rocks seen in this section.

The upper volcanic formation, to be described in the sequel, is traversed by numerous dikes, which could not be expressed on this small scale. The vertical lines in the lower formation represent a few of the perpendicular dikes which abound there. Countless others, inclined and tortuous, are found penetrating the same rocks. The five outliers of somewhat pyramidal shape, at the bottom of the Caldera (on each side of *m*), agree in structure and composition with the upper formation, and may have subsided into their present position, if the Caldera was caused by engulphment, or may have slid down in the form of land-slips, if the cavity be attributed chiefly to aqueous erosion.

In the description above given of the section (fig. 646.), the cliffs which wall in the Caldera are spoken of as consisting of two formations. Of these the uppermost alone gives rise to vertical precipices, from the base of which the lower descends in steep slopes, which, although they have the external aspect of taluses, are not in fact made up of broken materials, or of ruins detached from the higher rocks, but consist of rocks in place. Both formations are of volcanic origin, but they differ in composition and structure. In the upper, the beds consist of agglomerate, scoriæ, lapilli, and lava, chiefly basaltic, the whole dipping outwards, as if from the axis of the original cone, at angles varying from 10 to 28 degrees. The solid lavas do not constitute more than a fourth of the entire mass, and are divided into beds of very variable thickness, some scoriaceous and vesicular, others more compact, and even in some cases rudely columnar. All these more stony masses are seen to thin out and come to an end wherever they can be traced horizontally for a distance of a quarter of a mile, and usually sooner. Coarse breccias or agglomerates predominate in the lower part, as if the commencement of the second series of rocks marked an era of violent gaseous explosions. Single beds of this aggregate of angular stones and scoriæ attain a thickness of from 200 to 300 feet. They are united together by a paste of volcanic dust or spongiform scoriæ.

At one point on the right side of the great Barranco, near its exit from the Caldera, we observed in the boundary precipice a lofty column of amorphous and scoriaceous rock in which the red or rust-coloured scoriæ are as twisted and ropy as any to be seen on the slopes of Vesuvius; seeming to imply that there was here an ancient vent or channel of discharge subsequently buried under the products of newer eruptions. Countless dikes, more or less vertical, consisting chiefly of basaltic lava, traverse the walls of the Caldera, some of them terminating upwards, but a great number reaching the very crest of the ridge, and therefore having been posterior in origin to the whole precipice.

We could not discover in any one of the fallen masses of agglomerate which strewed the base of the cliffs a single pebble or waterworn fragment. Each imbedded stone is either angular or, if globular, consists of scoriæ more or less spongy, and evidently not owing its shape to attrition. It would be impossible to account for the absence of waterworn pebbles if the coarse breccia in question had been spread by aqueous agency over a horizontal area co-extensive with the Caldera and the volcanic rocks which surround it. The only cause known to us capable of dispersing such heavy fragments, some of them 3, 4, or 6 feet in diameter, without blunting their edges, is the power of steam, unless indeed we could suppose that ice had co-operated with water in motion; and the interference of ice cannot be suspected in this latitude (28° 40′), especially as I looked in vain for signs of glacial action here and in the other mountainous regions of the Canary Islands.

The lower formation of the Caldera is, as before stated, equally of igneous origin. It differs in its prevailing colour from the upper, exhibiting a tea-green and in parts a light yellow tint, instead of the usual brown, lead-coloured, or reddish hues of basalt and its associated scoriæ. Beds of a light greenish tuff are common, together with trachytic and greenstone rocks, the whole so reticulated by dikes, some vertical, others oblique, others tortuous, that we found it impossible to determine the general dip of the beds, although at the head of the great gorge or Barranco they certainly dip outwards, or to the south, as stated by Von Buch. But in following the section down the same ravine, where the mountain called Alejanado (*d*, figs. pp. 498. and 501.) is cut through, and where the rocks of the lower formation are very crystalline, we found what is not alluded to by the Prussian geologist, that the beds exposed to view in cliffs 1500 feet high have an anticlinal arrangement, exhibiting first a southerly and then a northerly dip at angles varying from 20 to 40 degrees (see section, fig. 646. at *k*.). Hence we may presume that the older strata must have undergone great movements before the upper formation was superimposed. No organic remains having been discovered in the older series, we cannot positively decide whether it was of subaerial or submarine origin. We can only affirm that it has been produced by successive eruptions, chiefly of felspathic lavas and tuffs. Many beds which probably consisted at first of soft tuffs have been much hardened by the contact of dikes and apparently much altered by other plutonic influences, so that they have acquired a semicrystalline and almost metamorphic character.

The existence of so great a mass of volcanic rocks of ancient date on the exact site of an equally vast accumulation of comparatively modern lavas and scoriæ is peculiarly worthy of notice as a general phenomenon observed in very different parts of the globe. It proves that, notwithstanding the fact in the past history of volcanos that one region after another has been for ages and has then ceased to be the chief theatre of igneous action, still the activity of subterranean heat may often be persistent for more than one geological period in the same place, relaxing perhaps its energies for a while, but then breaking out afresh with an intensity as great as ever.

We have still to consider the mode of origin of the higher volcanic mass, or the upper series of rocks with which the peculiar form of the Caldera is more intimately connected. The principal question here arising is this, whether the mass was dome-shaped from the beginning, having grown by the superposition of one conical envelope of lava and ashes formed over another, or whether, as Von Buch and his followers imagine, its component materials were first spread out in horizontal or nearly horizontal deposits and then upheaved at once into a dome-shaped mountain with a caldera in its centre. According to the first hypothesis the cone was built up gradually, and completed with all its beds dipping as now, and traversed by all its dikes, before the Caldera originated. According to the other, the Caldera was the result of the same movements which gave a dome-shaped structure to the mass, and which caused the beds to be highly inclined; in other words, the cone and the Caldera were produced simultaneously. So singularly opposite are these views that the principal agency introduced by the one theory is upheaval, by the other subsidence. The very name of "Elevation Craters" points to the kind of movement to which one school attributes the origin of a cone and caldera; whereas the chief agencies appealed to by the other school are gaseous explosions, engulphment, and aqueous denudation.

The favourable reception of the doctrine of upheaval has arisen from the following circumstances. Streams of lava, it is said, which run down a declivity of more than three degrees are never stony; and, if the slope exceed five or six degrees, they are mere shallow and narrow strings of vesicular or fragmentary slag. Whenever, therefore, we find parallel layers of stony lava, especially if they be of some thickness, high up in the walls of a caldera, we may be sure that they were solidified originally on a very gentle slope; and if they are now inclined at angles of 10°, 20°, or 30°, not only they, but all the interstratified beds of lapilli, scoriæ, tuff, and agglomerate, must have been at first nearly flat and must have been afterwards lifted up with the solid beds into their present position. It is supposed that such a derangement of the strata could scarcely fail to give rise to a wide opening near the centre of upheaval, and in the case of Palma, the Caldera (which Von Buch called "the hollow axis of the cone") may represent this breach of continuity.

Among other objections to the elevation-crater theory often advanced and never yet answered are the following: — First, in most calderas, as in Palma, the rim of the great cavity and the circular range of precipices surrounding it remain entire and unbroken on three sides, whereas it is difficult to conceive that a series of volcanic strata 2000 or 3000 feet thick could have once extended over an area six or seven miles in its shortest diameter and then have been upraised bodily, so that the beds should dip at steep angles towards all points of the compass from a centre, and yet that no great fractures should have been produced. We should expect to see some open fissures on every side, widening as they approach the caldera. The dikes, it is true, do undoubtedly attest many dislocations of the mass, which have taken place at successive and often distant periods. But none of them can have belonged to the supposed period of terminal and paroxysmal upheaval, for, had the caldera existed when they originated, the melted matter now solidified in each dike must, instead of filling a rent, have flowed down into the caldera, tending so far to obliterate the great cavity.

The second objection is the impossibility of imagining that so vast a series of agglomerates, tuffs, stratified lapilli, and highly scoriaceous lavas could have been poured out within a limited area without soon giving rise to a hill, and eventually to a lofty mountain. Such heavy angular fragments as are seen in the agglomerates, single beds of which are sometimes 200 or 300 feet thick, must when hurled into the air have fallen down again near the vent, and would be arranged in inclined layers dipping outwards from the central axis of eruption. It is in perfect accordance with this hypothesis that we should behold agglomerates, lapilli, and scoriæ predominating in the walls of the Caldera; whereas in the ravines nearer the sea, where the inclination of the beds has diminished to 10 and even to 5 degrees, the proportion of stony as compared to fragmentary materials is precisely reversed. It is also natural that the dikes should be most numerous where the ejectamenta are to the more solid beds in the proportion of 3 to 1, as at *b*, fig. 645. p. 500.; while the dikes are few in number where the stony lavas predominate (as at *c*, ibid.). Many of the scoriaceous beds at *b* may be the upper extremities of currents which became stony and compact when they reached *c*, and flowed over a more level country; but this suggestion cannot be assented to by the advocates of the upheaval theory, for it assumes the existence of a cone long before the time had arrived for the catastrophe which according to their views gave rise to a conical mountain.

If, however, we reject the doctrine that the beds were tilted by a movement posterior to the accumulation of all the compact and fragmentary rocks, how are we to account for the steepness of the dip of some stony lavas high up in the walls of the Caldera? These masses are occasionally 50 or 100 feet thick, of lenticular shape, as seen in the cliffs from below, and to all appearance parallel to the associated layers of scoriæ and lapilli. But unfortunately no one can climb up and determine how far the supposed parallelism may be deceptive.

The solid beds extend in general over small horizontal spaces, and some of them may possibly be no other than intrusive lavas, in the nature of dikes, more or less parallel to the layers of ejectamenta. Such lavas, when the crater was full, may have forced their way between highly inclined beds of scoriæ and lapilli. We know that lava often breaks out from the side or base of a cone, instead of rising to the rim of the crater. Nevertheless one or two of the stony masses alluded to seemed to me to resemble lavas which had flowed out superficially. They may have solidified on a broad ledge formed by the rim of a crater. Such a rim might be of considerable breadth after a partial truncation of the cone. And some lavas may now and then have entirely filled up the *atrium*, or what in the case of Somma and Vesuvius is called the *atrio del cavallo*, that is to say, the interspace between the old and new cone. When by the products of new eruptions a uniform slope has been restored, and the two cones have blended into one (see *e*, *d*, *c*, fig., p. 515.), the next breaking down of the side of the mountain may display a mass of compact rock of great thickness in the walls of a caldera, resting upon and covered by ejectamenta. Other extensive wedges of solid lava will be formed on the flanks of every volcanic mountain by the interference of lateral, or, as they are often termed, parasitic cones, which check or stop the downward flow of lava, and occasionally offer deep craters into which the melted matter is poured.

By aid of one or all the processes above enumerated we may certainly explain a few exceptional cases of intercalated stony beds, in the midst of others of a loose and scoriaceous nature, the whole being highly inclined. But to account for a succession of compact and truly parallel lavas having a steep dip, we may suppose that they flowed originally down the flanks of a cone sloping at angles of from 4 to 10 degrees, as in many active volcanos, and that they acquired subsequently a steeper inclination. It would be rash to assume the entire absence of local disturbances during the growth of a volcanic mountain. Some dikes are seen crossing others of a different composition, marking a distinctness in the periods of their origin. The volume of rock filling such a multitude of fissures as we see indicated by the dikes in Palma must be enormous; so that, could it be withdrawn, the mass of ejectamenta would collapse and lose both in height and bulk. The injection, therefore, of all this matter in a liquid state must have been attended by the gradual distension of the cone, the increase of which I have elsewhere compared both to the exogenous and endogenous growth of a tree, as it has been effected alike by external and internal accessions.

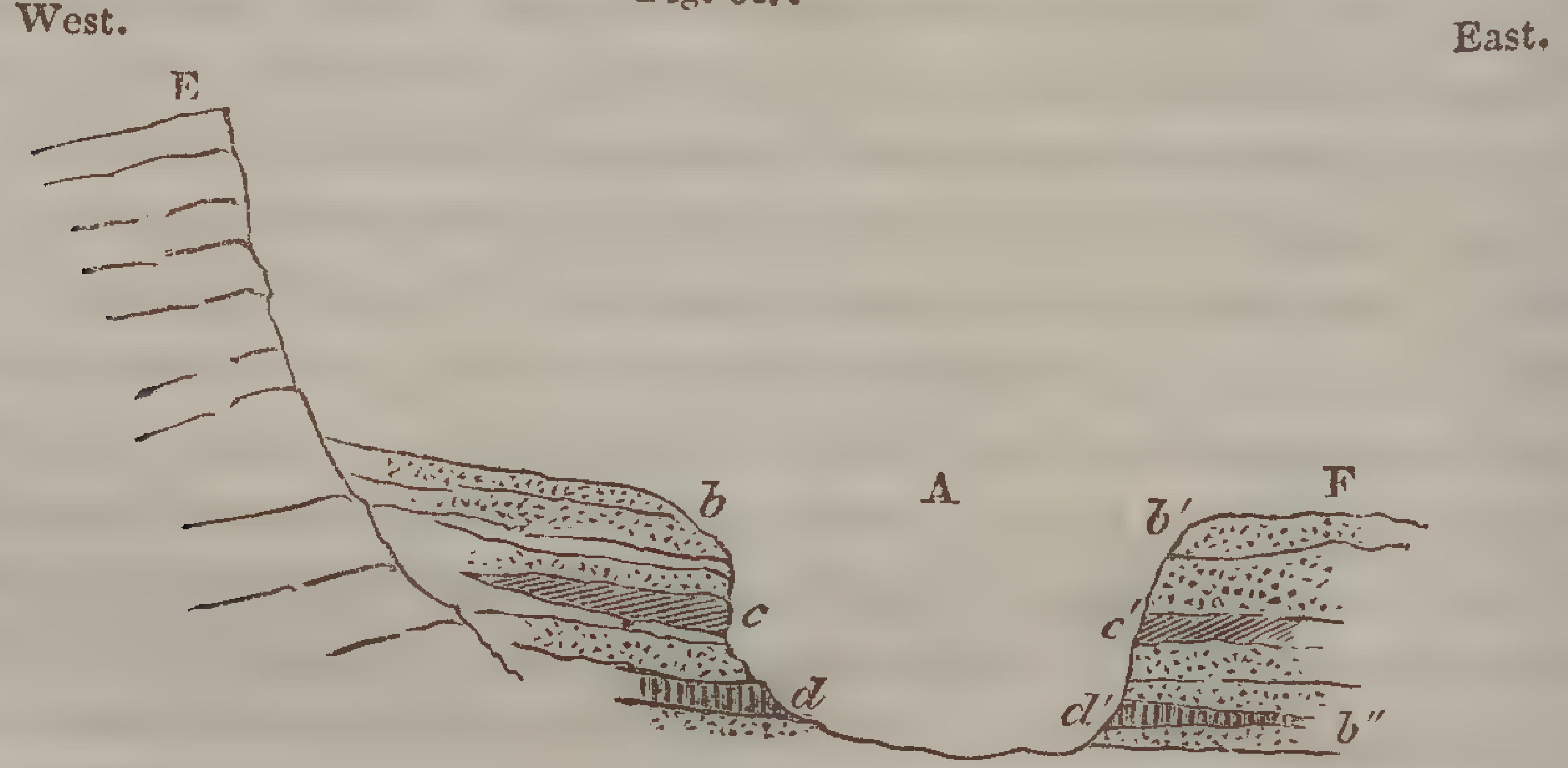
But the acquisition of a steeper dip by such reiterated rendings and injections of a cone is altogether opposed to the views of those who defend the upheaval hypothesis, because it draws with it the conclusion that the slopes were always growing steeper and steeper in proportion as the cone waxed older and loftier. Once admit this, and it follows, that the upper layers of solid lava must have con-formed to surfaces already inclined at angles of 20, or, in the case of the Caldera of Palma, 28 degrees.

For this reason the defenders of the upheaval hypothesis are consistent with themselves in assigning the whole movement by which the strata, whether solid or incoherent, have been tilted, exclusively to one terminal catastrophe. The whole development of subterranean force is represented as the last incident in every series of volcanic operations, the closing scene of the drama; and the sudden and paroxysmal nature of the catastrophe is inferred from the absence of all signs of successive and intermittent action so characteristic of the antecedent volcanic phenomena.

I have alluded to an opinion entertained by some able geologists, that no lava can acquire any degree of solidity if it flows down a declivity of more than three degrees. This doctrine I believe to be erroneous. The lava which has flowed from the cone of Llarena near Port Orotava, in Teneriffe, is very columnar in parts, and yet has descended a slope of six degrees. Another stream of recent aspect near the town of El Passo, in Palma, has a general inclination of ten degrees, and is remarkable for the depth and extent of the large basin-shaped hollows, 20, 30, and 35 feet deep, seen everywhere on its surface. Whenever another lava-current shall flow down over this one, although its average inclination will be the same, it must fill up all these inequalities, and in doing so must give rise to masses of compact and solid rock 20 or 30 feet thick, resting upon and encircled by vesicular lava. Other lavas north-east of Fuencaliente at the southern extremity of Palma, so modern as to be still black and uncovered with vegetation, descend slopes of no less than 22 degrees, and yet contain large masses of compact stone, formed chiefly on the sides of tunnel-shaped cavities, 15 or 20 feet deep, in which one layer has solidified within another on the walls of these channels, while in the central part the lava seems to have remained fluid so as to run out of the tunnel, leaving an arched cavity, the roof of which has in most cases fallen in. The strength of the enveloping crust of scoriæ at the lower end of a lava-current in which one of these tunnels existed may have been sufficient to arrest the progress of the stream for hours or days, and during that time solidification may have occurred under great hydrostatic pressure.

Before taking leave of Palma, we have yet to consider another distinct point, namely, what amount of denudation has taken place in the Caldera, and its environs. Assuming that the great cavity or some part of it may have originated in the truncation of a cone in the manner before suggested, to what extent has its shape been subsequently enlarged or modified by aqueous erosion? It will be remembered that a conglomerate of well-rounded pebbles, no less than 800 feet thick, was spoken of as visible in the great Barranco (see description of section, pp. 501, 502.). That conspicuous deposit, 3 or 4 miles in length, was evidently derived from the destruction of rocks like those in the Caldera, for the present torrent brings down annually similar stones of every size, some very large, and rounds them by attrition in its channel. By what changes in the configuration of the island after the old volcano and its Caldera were formed was so vast a thickness of gravel formed, to be afterwards cut through to a depth of 800 feet? The ravine through which the torrent now flows has been excavated to that depth through the old conglomerate. The occurrence of two or three layers of contemporaneous lava, intercalated between the strata of puddingstone, ought not to surprise us; for even in historical times eruptions have been witnessed in the southern half of Palma. Such basaltic lavas, one of them columnar in structure, have not come down from the Caldera, but from cones much nearer the sea, and immediately adjoining the Barranco, like the cone of Argual (see map, p. 499.) and others. These lavas, of the same age as the conglomerate, consist of three or four currents of limited extent, for in many parts of the river-cliffs no volcanic formation is visible on either bank. On the right bank of the Barranco, the conglomerate, when traced westward, is soon found to come to an end as it abuts against the lofty precipice E (fig. 647.), which is a prolongation of the western wall of the Caldera. Its extent eastward from *b′*, may be more considerable, but cannot be ascertained, as it is concealed under modern scoriæ and lava spread over the great platform, F.

Fig. 647.



A. Ravine or Barranco de las Angustias, near its termination in Palma.
b, b′, b″. Conglomerate, 800 feet thick in parts.
c, c′. Lava intercalated between the beds of conglomerate.
d, d′. Another and older current of basaltic lava, columnar in parts.
E. Cliff of ancient volcanic rocks of the Upper Formation (p. 504.), a prolongation of the western wall of the Caldera.
F. Platform on which the town of Argual stands.

As we could find no organic remains in the old gravel, we have no positive means of deciding whether it be fluviatile or marine. The height of its base above the sea, where it is 800 feet thick, may be about 350 feet, but patches of it ascend to elevations of 1000 and 1500 feet near the top of the Barranco, as shown at *k*, &c., in section, fig. 646., p. 501. Such a mass of gravel, therefore, bears testimony to the removal of a prodigious amount of materials from the Caldera by the action of water. Whether a river or the sea was the transporting agent, it is obvious that a large portion of the volcanic materials, consisting of sand, lapilli, and scoriæ, before described

(p. 502.), as belonging to the upper formation in the Caldera, would leave behind them few pebbles. Nearly all of these perishable deposits would be swept down in the shape of mud into the Atlantic. Even the hard rounded stones, since they were once angular and are now ground down into pebbles, must have lost more than half their original bulk, and bear witness to large quantities of sedimentary matter consigned to the bed of the ocean. We saw in the Caldera blocks of huge size thrown down by cascades from the upper precipices during the melting of the snows, a fortnight before our visit, and much destruction was likewise going on in the lower set of rocks by the same agency. We also learnt that a great flood rushed down the Barranco in the spring of 1854, shortly before our arrival, damaging several houses and farms, and I have therefore no doubt that the erosive power even of rain and river water, aided by earthquakes, might in the course of ages empty out a valley as large as the Caldera, although probably not of the same shape. I am disposed to attribute the circular range of cliffs surrounding the Caldera to volcanic action, because they forcibly reminded me of the precipices encircling three sides of the Val del Bove, on Etna; and because they agree so well with Junghuhn's description of the "old crater-walls" of active volcanos in Java, some of which equal or surpass in dimensions even the Caldera of Palma. The latter may have consisted at first of a true crater, enlarged afterwards into a caldera by the partial destruction of a great cone; but, if so, it has certainly been since modified by denudation. Nor can any geologist now define how much of the work has been accomplished by aqueous, and how much by volcanic agency. The phenomenon of a river cutting its channel through a dense mass of ancient alluvium formed during oscillations in the level of the land is not confined to volcanic countries, and I need not dwell here on its interpretation, but refer to what was said in the 7th chapter. (See p. 84.).

There remains, however, another question of high theoretical interest; namely, whether the denudation was marine or fluviatile. It was stated that the materials of the great cone or assemblage of cones in the north of Palma are of subaerial origin, as proved by the angularity of the fragments of rock in the agglomerates; but it may be asked, whether, when the Caldera was formed long afterwards, it may not, like the crater of St. Paul's (fig. 649., p. 513.), have had a communication with the sea, which may have entered by the great Barranco, and if, after a period of partial submergence, the island may not then have risen again to its original altitude. In such a case the retiring waters might leave behind them a conglomerate, partly of river-pebbles, collected at the points where the torrent successively entered the sea, and partly of stones rounded by the waves. The torrent may have finally cut a deep ravine in the gravel and associated lavas when the land was rising again. Such oscillations of level, amounting to more than 2000 feet, would not be deemed improbable by any geologists, provided they enable us to explain more naturally than by any other causation, the origin of the physical outlines of the country. As to the fact that no marine shells have yet been discovered in the conglomerate, sufficient search has not yet been made for them to entitle us to found an argument on such negative evidence. At the same time I confess, that, having found sea-shells and bryozoa abundantly in certain elevated marine conglomerates in the Grand Canary, before I visited Palma, and being unable to meet with any in the Barranco de las Angustias, I regarded the old gravel when I was on the spot as of fluviatile origin. Such inferences are always doubtful in the absence of more positive data, and the intervention of the sea will unquestionably account for some phenomena in the configuration of the Caldera and Barranco more naturally than river action. For example, we have the lofty cliff E, fig. p. 508. already mentioned, and *c*, *f*, map, p. 498., extending four or five miles from the Caldera to the sea on the right bank of the Barranco; and no cliff of corresponding height or structure on the other bank, where for miles towards the south-east there is the platform F, fig. p. 508. supporting several minor volcanic cones. The sea might be supposed to leave just such a cliff as E, after cutting away a portion of the south-western extremity of the old dome-shaped mountain in the north of Palma, whereas a torrent or river would leave a cliff of similar structure and nearly equal height on both banks. As to the fact of the old conglomerate ascending an inclined plane, *i*, *l*, *k*, p. 501., from the sea-level to an elevation of about 1500 feet, near the entrance of the Caldera, this is by no means conclusive in favour of fluviatile action, although some elevated patches of the same may in truth belong to an old river-bed; but in South America gravel-beds of marine origin have a similar upward slope, when followed inland, and the cause of such an arrangement has been explained in a satisfactory manner by Mr. Darwin.*

Another argument in favour of marine denudation may be derived from that peculiar feature in the configuration of Palma, before alluded to, called the pass of the Cumbrecito (*e*, fig. 646., p. 501.), forming a notch in the uppermost line of precipices surrounding the Caldera. This break divides the mountain called Alejenado, *d*, fig., p. 501., from the eastern wall *c f*, and cuts quite through the upper formation; yet the range of precipice *f*, *e*, on the eastern side of the Caldera is continued uninterruptedly, and retains its full height of 1500 or 2000 feet above its base, to the southward of the Cumbrecito, or from *e* towards *a*, map, fig. 642., p. 498. In this prolongation of the cliff for half a mile southward beds of volcanic matter and dikes are seen, as in the walls of the Caldera.

The indentation forming the pass of the Cumbrecito, *e*, p. 501., has more the appearance of an old channel, such as a current of water may have excavated, than of a rent or a chasm caused by a fault. In case of a fault the lower formation would not be persistent and uninterrupted across the Cumbrecito, constituting the watershed; but would have sunk down and have been replaced by the upper basaltic

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* Geolog. Observ., South America, p. 43.

rocks. If we could assume that the sea once entered the Caldera here as well as by the great Barranco, it might have produced such a breach as *e*, and such an extension of the line of cliffs as that now observable between *e* and *a*, map, p. 498. without any corresponding cliff to the westward of *e*, *a*.

Yet we could discover no elevated outliers of conglomerate to attest the supposed erosion at the Cumbrecito, which is about 3500 feet above the level of the sea. It might also be objected to the hypothesis of marine denudation in Palma, that there are no ranges of ancient sea-cliffs on the external slopes of the island. The flanks of the mountain, except where it is furrowed by ravines or broken by lateral cones, descend to the sea with a uniform inclination. In reply to such a remark, I may observe that we do not require the submergence of the uppermost 3000 feet of the old cone in order to allow the sea to enter both the great Barranco and the Cumbrecito and to flow into the Caldera. It would be enough to suppose the land to sink down so as to permit the waves to wash the base of the basaltic cliffs in the interior of the Caldera, and to wear a passage through the Cumbrecito where there may have been always a considerable depression in the outline of the upper formation. But would not the same waves which had power to form in the Barranco a mass of conglomerate 800 feet thick have left memorials of their beach-action on the external slope of the island? No such monuments are to be seen. It may be said, in explanation, — first, that cliffs are not so easily cut on the side of an island towards which the beds dip as on the side from which they dip; secondly, if some small cliffs and sea-beaches had existed, they may have been subsequently buried under showers of ashes and currents of lava proceeding from lateral cones during eruptions of the same date as those which were certainly contemporaneous with the conglomerate of the great Barranco.

On the eastern coast of Palma, about half a mile from the sea, in the ravine of Las Nieves, not far from Santa Cruz, we observed a conglomerate of well-rounded pebbles having a thickness of 100 feet, covered by successive beds of lava, also about 100 feet thick. In this instance the ancient gravel beds occupy a position very analogous to the buried cone, S. P., fig. 645., p. 500. When in Palma, I conceived them to be of fluviatile origin; but, whether marine or freshwater, it must be admitted that the superposition of so dense an accumulation of lavas to a mass of conglomerate 100 feet thick shows how easily the outer slopes of the island may have been denuded by the sea and yet display no superficial signs of marine denudation, every old beach or delta once at the mouth of a torrent being concealed under newer volcanic outpourings.

Since the cessation of volcanic action in the north of Palma, the most frequent eruptions appear to have taken place in a line running north and south, from *a* to Fuencaliente, map, p. 498.; one of the volcanos in this range, called Verigojo, *g*, being no less than 6565 English feet high. The lavas descending from several vents in this chain reach the sea both on the east and west coast, and are many of them nearly as naked and barren of vegetation as when they first flowed. The tendency in volcanic vents to assume a linear arrangement, as seen in the volcanos of the Andes and Java on a grand scale, is exemplified by the cones and craters of this small range in Palma. It has been conjectured that such linearity in the direction of superficial outbreaks is connected with deep fissures in the earth's crust communicating with a subjacent focus of subterranean heat.

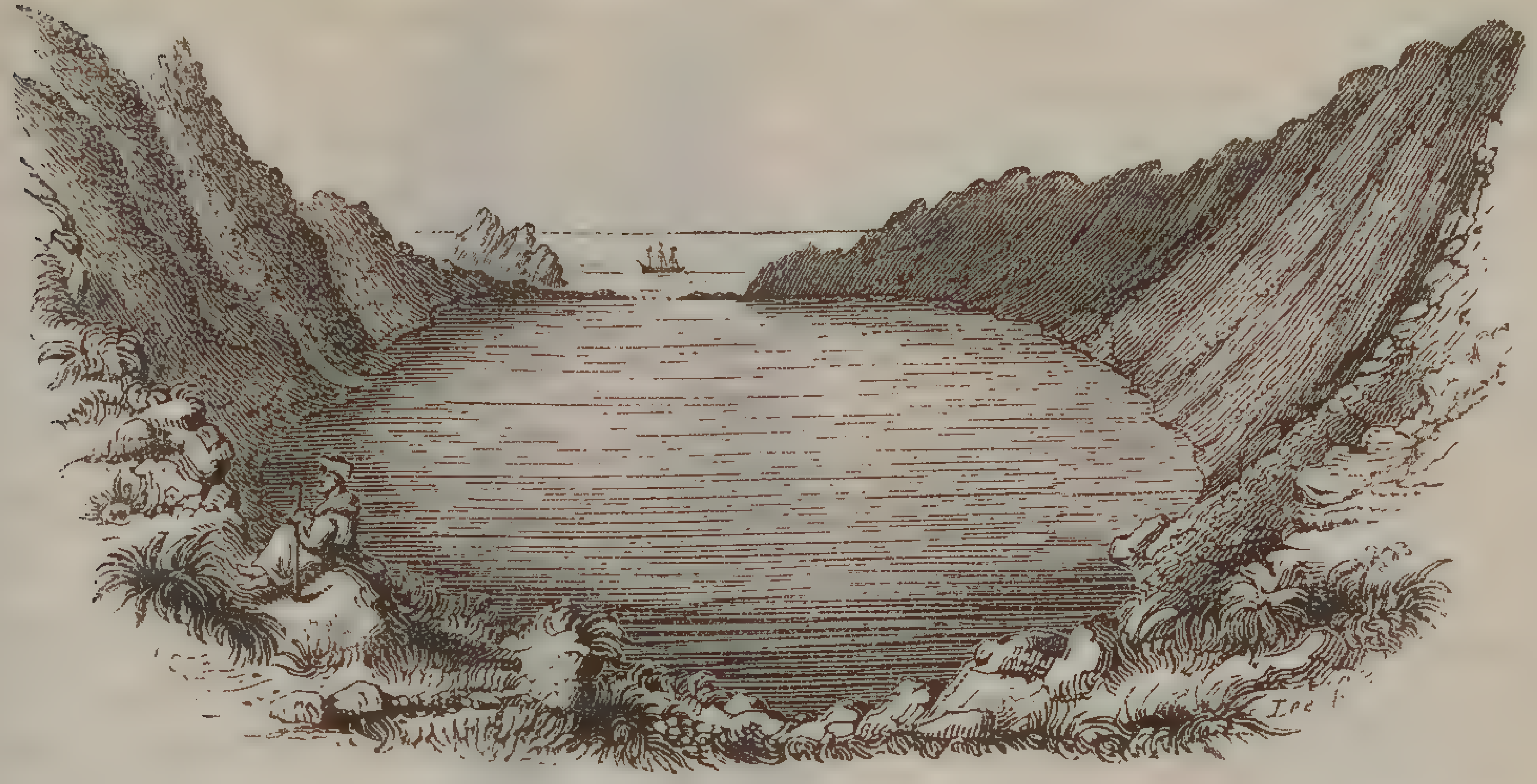
By discussing at so much length the question whether the sea may or may not have played an important part in enlarging the Caldera of Palma, I have been desirous at least to show how many facts and observations are required to explain the structure and configuration of such volcanic islands. It may be useful to cite, in illustration of the same subject, the present geographical condition of St. Paul's or Amsterdam Island, in the Indian Ocean, midway between the Cape of Good Hope and Australia.

Fig. 648.

Map of the Island of St. Paul, in the Indian Ocean, lat. 38° 44′ S., long. 77° 37′ E., surveyed by Capt. Blackwood, R.N., 1842.

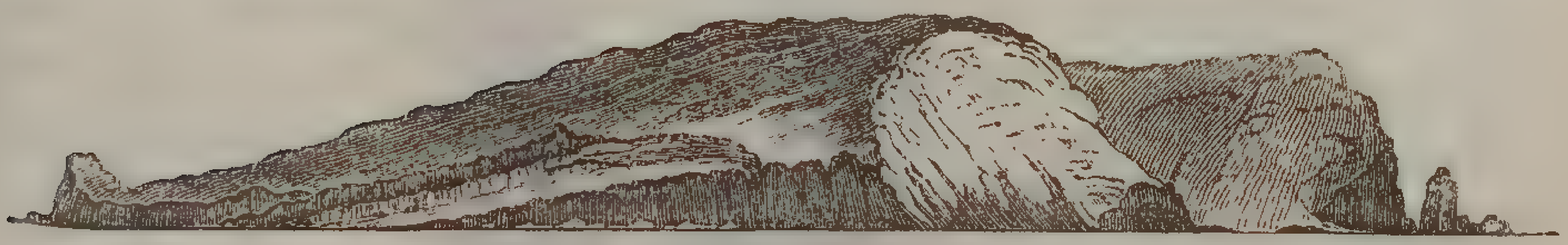
In this case the crater is only a mile in diameter and 180 feet deep, and the surrounding cliffs where loftiest about 800 feet high, so that in regard to size such a cone and crater are insignificant when compared to the cone and Caldera of Palma or to such volcanic domes as Mounts Loa and Kea in the Sandwich Islands. But the Island of St. Paul exemplifies a class of insular volcanos into which

Fig. 649.



View of the Crater of the Island of St. Paul.

Fig. 650.



Side view of the Island of St. Paul (N.E. side). Nine-pin rocks two miles distant. (Captain Blackwood.)

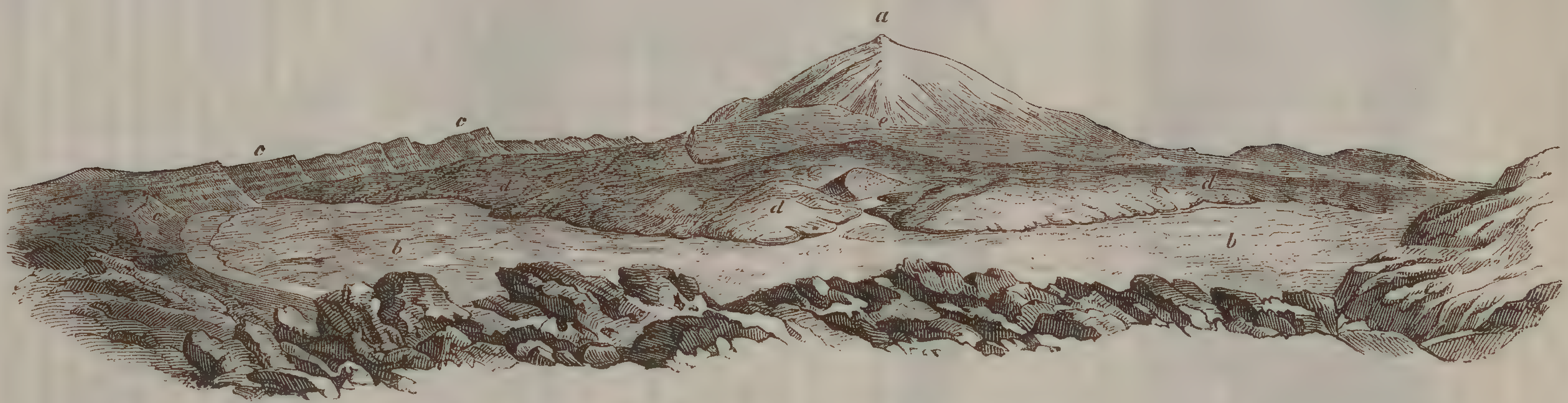
the ocean now enters by a single passage. Every crater must almost invariably have one side much lower than all the others, namely that side towards which the prevailing winds never blow, and to which, therefore, showers of dust and scoriæ are rarely carried during eruptions. There will also be one point on this windward or lowest side more depressed than all the rest, by which in the event of a partial submergence the sea may enter as often as the tide rises, or as often as the wind blows from that quarter. For the same reason that the sea continues to keep open a single entrance into the lagoon of an atoll or annular coral reef, it will not allow this passage into the crater to be stopped up, but will scour it out at low tide, or as often as the wind changes. The channel, therefore, will always be deepened in proportion as the island rises above the level of the sea, at the rate perhaps of a few feet or yards in a century.

The crater of Vesuvius in 1822 was 2000 feet deep; and, if it were a half-submerged cone like St. Paul, the excavating power of the ocean might in conjunction with a gradual upheaving force give rise to a large caldera. Whatever, therefore, may have been the nature of the forces, igneous or aqueous, which have shaped out the Val del Bove on Etna or the deep abyss called the Caldera in the north of Palma, we can scarcely doubt that many craters have been enlarged into calderas by the denuding power of the ocean, whenever considerable oscillations in the relative level of land and sea have occurred.

Peak of Teneriffe.— The accompanying view of the Peak, taken

Fig. 651.

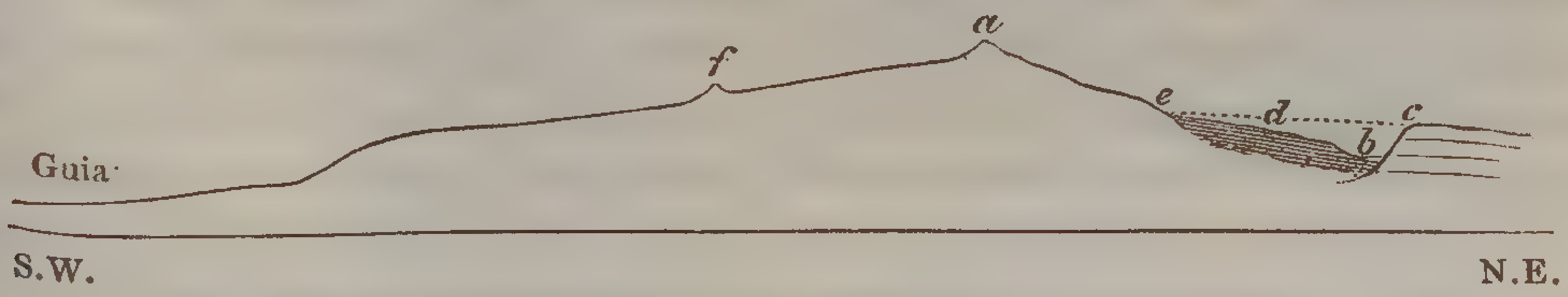
VIEW OF THE PEAK OF TENERIFFE AND THE CAÑADAS FROM THE NORTH-EAST.



a. The Peak, which is about 4000 feet above the level of the plain *b*.
b, *b*. The atrium, or Las Canadas.
c, *c*. Wall of the Caldera, or cliff bounding the atrium.
d, *d*. Lavas which have flowed from the Peak or from lateral cones.
e. A point corresponding to *e*, in section, fig. 652., p. 515.

from sketches made by Mr. Hartung and myself during our visit to Teneriffe in 1854, will show the manner in which that lofty cone is encircled on more than two sides by what I consider as the ruins of an older cone, chiefly formed by eruptions from a summit which has disappeared. That ancient culminating point from which one or more craters probably poured forth their lavas and ejectamenta may not have been placed precisely where the present peak now rises, and may not have had the same form, but its position was probably not materially different. The great wall or semicircular range of precipices, *c c*, surrounding the atrium, *b b*, is obviously analogous to the walls of a Caldera like that of Palma; but here the cliffs are insignificant in dimensions when compared to those in Palma, being in general no more than 500 feet high and rarely exceeding 1000 feet. The plain or atrium, *b b*, figs. 651. and 652., lying at the base of the cliffs, is here called Las Cañadas, and is covered with sand and pumice thrown out from the Peak or from craters on its flanks. Copious streams of lava, *d d*, have also flowed down from lateral openings, especially from a crater called the Chahorra, *f*, fig. 652., which is not seen in the view, fig. 651., as it is hidden by the Peak. The last eruption was as late as the year 1798.

Fig. 652.



Section through part of Teneriffe, from N.E. to S.W. On a true scale; as given in Von Buch's "Canary Islands."

a. Peak of Teneriffe.
b. The Cañadas or atrium.
c. Cliff bounding the atrium.
d. Modern lavas.
f. Cone and crater of Chahorra.

To what extent the lavas, *d d*, figs. 651. and 652., may have narrowed the circus or atrium, *b*, or taken away from the height of the cliff *c*, no geologist can determine for want of sections; but should the Peak and the Chahorra continue to be active volcanos for ages, the new cone, *a*, might become united with the old one, and the lava might flow first from *e* to *c* and then from *a* to *c*, fig. 652., so that the slope might begin to resemble that formed by lavas and ejectamenta from the summit *a* to Guia, on the south-western side of the cone.

Madeira.—Every volcanic island, so far as I have examined them, varies from every other one in the details of its geographical and geological structure so greatly that I have no expectation of finding any simple hypothesis, like that of "elevation craters," applicable to all or capable of explaining their origin and mode of growth. Few islands, for example, resemble each other more than Madeira and Palma, inasmuch as both consist mainly of basaltic rocks of subaerial origin, but, when we compare them closely together, there is no end of the points in which they differ.

The oldest formation known in Madeira is of submarine volcanic origin, and referable perhaps to the Miocene tertiary epoch. Tuffs and limestones containing marine shells and corals occur at S. Vicente on the northern coast, where they rise to the height of more than 1200 feet above the sea. They bear testimony to an upheaval to that amount, at least, since the commencement of volcanic action in those parts.

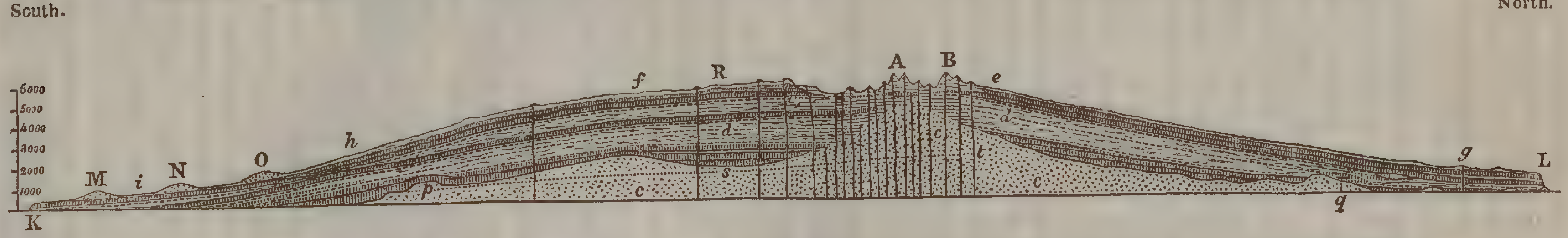
The pebbles in these marine beds are well rounded and polished, strongly contrasting in that respect with the angular fragments of similar varieties of volcanic rocks so frequent in the superimposed tuffs and agglomerates formed above the level of the sea.

The length of Madeira from east to west is about 30 miles, its breadth from north to south being 12 miles. The annexed section, fig. 653., drawn up on a true scale of heights and horizontal distances from the observations of Mr. Hartung and myself, will enable the reader to comprehend some of the points in which, geologically considered, Madeira resembles or varies from Palma. In the central region, at A, as well as in the adjoining region on each side of it, are seen, as in the centre of Palma, a great number of dikes penetrating through a vast accumulation of ejectamenta, *c*. Here also, as in Palma, we observe as we recede from the centre that the dikes decrease in number, and beds of scoriæ, lapilli, agglomerate, and tuff begin to alternate with stony lavas, *d d*, until at the distance of a mile or more from the central axis the volcanic mass, below *f h* and *e g*, consists almost exclusively of streams or sheets of basalt, with some red partings of ochreous clay or laterite, probably ancient soils. The darker lines indicate the predominance of these lavas which have flowed on the surface, and which, besides basalt, consist of various kinds of trap, and in some places of trachyte. The lighter tint, *c*, expresses an accumulation of scoriæ, agglomerate, and other materials, such as may have been piled up in the open air, in or around the chief orifices of eruption, and between volcanic cones.

The Pico Torres, A, more than 6000 feet high, is one of many central peaks, composed of ejected materials. By the union of the foundations of many similar peaks, ridges or mountain crests are formed, from which the tops of vertical dikes project like turrets above the weathered surface of the softer beds of tuff and scoriæ. Hence the broken and picturesque outline, giving a singular and romantic character to the scenery of the highest part of Madeira. North of A is seen Pico Ruivo (B), the most elevated peak in the island, yet exceeding by a few feet only the height of Pico Torres. It is similar in composition, but its uppermost part, 400 feet high, retains a more perfectly conical form, and has a dike at its summit with streams of scoriaceous lava adhering to its steep flanks. There are a great many such peaks east and west of A, which seem to be the ruins of cones of eruption, the materials of some at least having been arranged with a quâ-quâ-versal dip. Among these is Pico Grande, C, fig. 655., now half-buried under more modern lavas which have flowed round it. It is perhaps owing to the juxtaposition of such a multitude of cones or points of eruption, and the

Fig. 653.

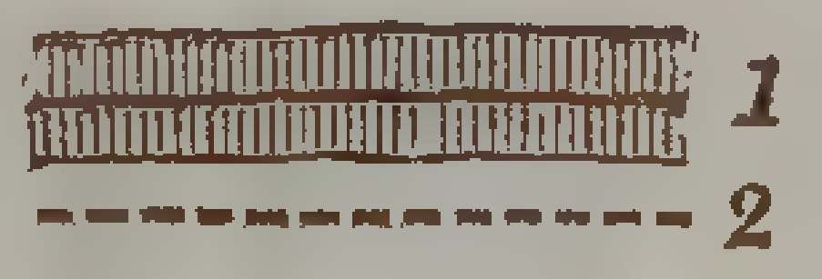
SECTION OF MADEIRA FROM NORTH TO SOUTH, OR FROM POINT S. JORGE TO POINT DA CRUZ, NEAR FUNCHAL.



Length of section twelve miles. Drawn on a true scale of heights and horizontal distances from the observations of C. Lyell and G. Hartung, 1853—4.

- *A.* Pico Torres (or Pico do Gatto), about 6050 feet high.
- *B.* Pico Ruivo; the highest mountain in Madeira; about 6060 feet high.
- *c.* Scoriæ, agglomerate, lapilli, tuff, and ejectamenta, with some highly scoriaceous lava.
- *d.* Alternations of lava with tuff and lapilli, or with parting layers of red clay (laterite). Under this same head of "alternations" must be included all the beds between R and *s*.
- *e.* Commencement of more highly inclined lavas on north side of Madeira; slope usually 10 degrees.
- *f.* Commencement of more highly inclined lavas on southern slope, usually at angle at 15 degrees.
- *g.* Dike of Jogo da Bola, in Ribeiro S. Jorge.
- *h.* Slope of beds 15 degrees, occasionally but rarely 20 degrees.

- *i.* Slope or dip of lavas 5 degrees.
- K. Point da Cruz, near Funchal.
- L. Point S. Jorge, on north coast.
- M. Pico da Cruz, 843 feet high; modern cone.
- N. Pico S. Martinho, 1100 feet high.
- O. Pico S. Antonio, 1440 feet.
- *p.* Buried cone in Ribeiro do Torreão.
- *q.* Lignite and leaf-bed.
- R. Pico S. Antonio, 5706 feet high.
- *p, s, t.* Line below which the rocks are not exposed to view. All below this line is given conjecturally.



The beds indicated by the sign No. 1. consist of lavas more or less stony, under which occur red clays or laterites, probably ancient soils (see p. 475.), represented by the interrupted lines, No. 2. These red bands, as well as the lavas, No. 1., are very numerous in nature, and for want of space a few only are introduced into the diagram.

interference of their lavas along the great east and west line of volcanic action, that we find the stony beds in the central region between *e* and *f*, fig. 653., nearly horizontal, or having a dip of no more than from 3 to 5 degrees instead of having a very steep inclination like those in the walls of the Caldera of Palma.

These level or slightly inclined beds often form platforms, such as that called the Paul da Serra (*a*, fig., p. 520.). But when we recede from the central axis, the lavas acquire an average slope of 10 degrees on the north (as between *e* and *g*, fig. 653.), and of 15 on the south between *f* and *h*. Nearer the sea again, as at *i* and L, where the most modern lavas occur, the dip diminishes to 5 degrees, and even to 3½, as at K, near Funchal. In this latter characteristic, however (the smaller inclination of the lavas near the sea, and their association there with modern cones of eruption, such as M, N, O), there is a strict analogy between Madeira and Palma. Buried cones of eruption also occur at many points, as at *p* and *q*, fig. 653., which have been overwhelmed by lavas flowing from the central region. The aggregate thickness of the more solid basalts alternating with tuffs rarely exceeds 1500 feet; but below Pico S. Antonio, or R, fig., p. 517., they attain a thickness of 3000 feet, being exposed to view on the sides of a deep valley called the Curral, presently to be mentioned.

As a general rule, the lavas of Madeira, whether vesicular or compact, do not constitute continuous sheets parallel to each other. When viewed in the sea-cliffs in sections transverse to the direction in which they flowed, they vary greatly in thickness, even if followed for a few hundred feet or yards, and they usually thin out entirely in less than a quarter of a mile. In the ravines which radiate from the centre of the island, the beds are more persistent, but even here they usually are seen to terminate, if followed for a few miles; their thickness also being very variable, and sometimes increasing suddenly from a few feet to many yards.

I saw no remains of fossil plants in any of the red partings or laterites above alluded to; but Mr. Smith, of Jordanhill, was more fortunate in 1840, having met with the carbonized branches and roots of shrubs in some red clays under basalt near Funchal. Nevertheless, Mr. Hartung and I obtained satisfactory evidence in the northern part of the island, in the ravine of S. Jorge, of the former existence of terrestrial vegetation, and consequently of the subaerial origin of a large portion of the lavas of Madeira. At *q* in the section (fig. 653.) the occurrence of a bed of impure lignite, covered by basalt, had long been known. Associated with it, we observed several layers of tuff and clay or hardened mud, in one of which leaves of dicotyledonous plants and of ferns abound. The latter, according to Mr. Charles J. F. Bunbury, are referable to the genera *Sphenopteris*, *Adiantum?*, *Pecopteris*, and *Woodwardia*, one of them having the peculiar venation of *Woodwardia radicans*, a species now common in Madeira. Among the dicotyledonous leaves, some are apparently of the myrtle family, the larger proportion having their surfaces smooth and unwrinkled, with a somewhat rigid and coriaceous texture, and with undivided or entire margins. "These characters," observes Mr. Bunbury, "belong to the laurel-type, and indicate a certain analogy between the ancient vegetable remains and the modern forests of Madeira, in which laurels and other evergreens abound, with glossy coriaceous and entire-edged leaves, while below them there is an undergrowth of ferns and other plants."

The lignite above mentioned and the leaf-bed occur at the height of 1000 feet above the level of the sea, and are overlaid by superimposed basalts and scoriæ, 1100 feet thick, implying the existence of an ancient terrestrial vegetation long before a large part of Madeira had been built up. The nature of the tuffs accompanying the lignite, together with some agglomerates in the vicinity, entitles us to presume that near this spot a series of eruptions once broke out. Nor is it improbable that there may have been here the crater of some lateral cone in which the lignite and leaf-bed accumulated; for, although craters are remarkably rare in Madeira, when we consider how considerable is the number of perfect cones, yet on the mountain called Lagoa, 2½ miles west of Machico, a crater as perfect as that of Astroni near Naples may be seen.

At the bottom of this circular cavity (fig. 654.), which is about 150 feet deep, is a plain about 500 feet in diameter, having a pond in the middle, towards which the plain slopes gently from all sides. Such ponds are often seen in the interior of extinct craters. Except in the middle it is shallow, and supports aquatic plants. Many leaves must also be blown into it from the surrounding heights when high winds prevail, so that a mass of peaty matter convertible into lignite may collect here.

Fig. 654.

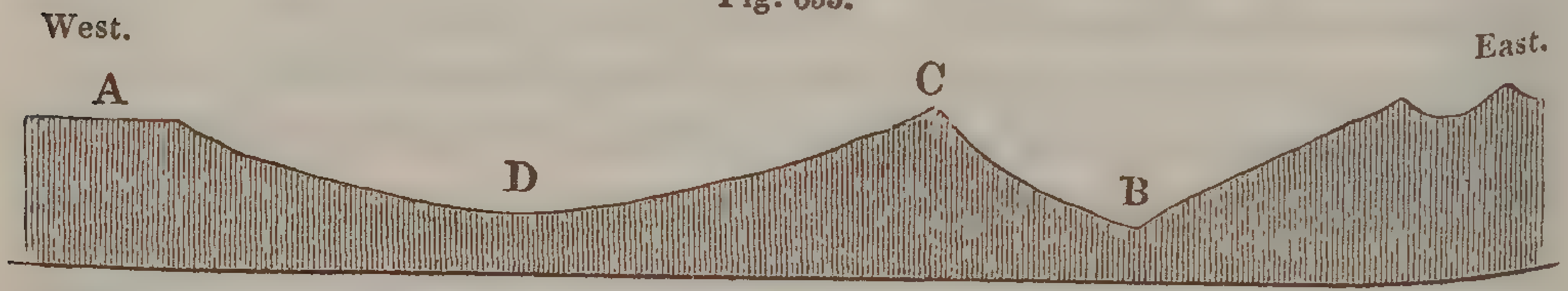
Crater of Lagoa, 2½ miles west of Machico, Madeira.

In this cut, taken from a sketch of my own, the depth of the crater may appear too great, unless it is borne in mind that there are no trees visible, and most of the bushes are of the Madeira whortle-berry (*Vaccinium Madeirense*) five or six feet high. Immediately behind the foreground an artificial mound is seen thrown up as a fence.

Had streams of lava descending from greater heights entered this Lagoa crater, they would have formed dense masses of compact rock cooling slowly under great pressure, like those now incumbent on the impure lignite of S. Jorge. The dip of the latter cannot be clearly determined, since it is exposed to view for too short a distance; and the same may be said of the leaf-bed, part of which may be traced lower down the ravine. It seems, however, to dip to the north or towards the sea conformably with the general inclination of the basaltic and tufaceous strata.

A deep valley, called the Curral (B, fig. 655.), surrounded by precipices from 1500 to 2500 feet high, and by peaks of still greater elevation, occurs in the middle of Madeira. It has been compared by some to a crater or caldera, for its upper portion is situated in the region where dikes and ejectamenta abound. The Curral, however, extends, without diminishing in depth, to below the region of numerous dikes, and it lays open to view all the beds R, *s*, fig. 653. Nor do the volcanic masses dip away in all directions from the Curral, as from a central point, or from the hollow axis of a cone. The Curral is in fact one only of three great valleys which radiate from the most mountainous district, a second depression, called the Serra d'Agoa (D, fig. 655.), being almost as deep. This cavity is also drained by a river flowing to the south; while a third valley, namely, that of the Janella, sends its waters to the north. The section alluded to (fig. 655.), passing through part of the axis of the island in an E. and W. direction, shows how the Curral and Serra d'Agoa, B and D, are separated by a narrow and lofty ridge, C, part of which is surmounted by the Pico Grande, before mentioned, nearly 5400 feet high. There is no essential difference between the shape of these three great valleys and many of those in the Alps and Pyrenees, where the valley-making process can have had no connection with any superficial volcanic action.

Fig. 655.



Section through the central region of Madeira, from East to West.

A. Part of the platform, called the Paul da Serra.
B. Curral; a valley, 3000 feet deep.
C. Pico Grande.
D. The valley of the Serra d'Agoa.

In the Alps, no doubt, as in other lofty chains, the formation of valleys has been greatly aided by subterranean movements, both gradual and violent, and by the dislocation of rocks. The same may be true of Madeira and of almost every lofty volcanic region; but, when we reflect that the central heights A and B, fig. 653., are more than 6000 feet above the sea, and that the waters flowing from them, swollen by melted snows, reach the sea by a course of not much more than 6 miles in the case of those draining the Curral, and by nearly as short a route in the Serra d'Agoa, we shall be prepared for almost any amount of denudation effected simply by subaerial erosion.

The general absence of water-worn pebbles in the tuffs underlying the Madeira lavas is very striking, and contrasts with the frequent occurrence of gravel-beds under so many of the Auvergne lavas. It simply proves that Madeira, like the volcanic mountains of Java, or like Mount Etna or Mona Loa in the Sandwich Islands, could not, for reasons before given p. 479., support a single torrent so long as eruptions were frequent on its slopes. The period, therefore, of fluviatile erosion must have been subsequent to the formation of the central nucleus of ejectamenta, *c*, fig., p. 517., and of the lavas *d*, ibid. When we infer that these were of supramarine origin as far down as the line *p*, *s*, *t*, and perhaps lower, it follows that a lofty island, 4000 feet or more in height, must have resulted, even if no upheaval had ever occurred.

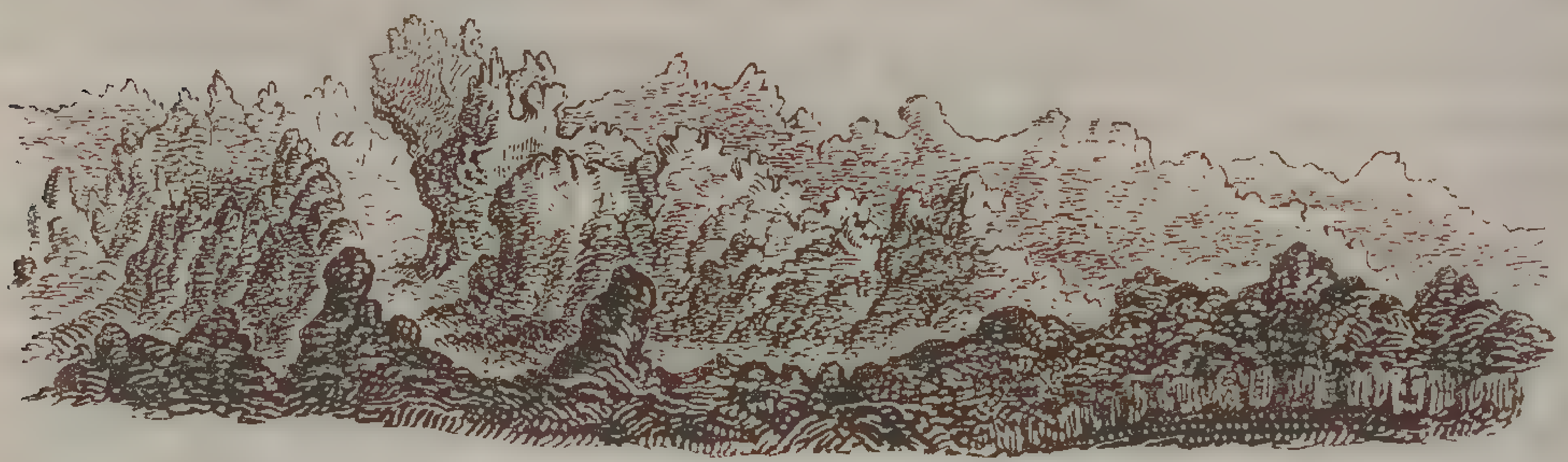
The movements which upraised the marine deposits of San Vicente may or may not have extended over a wide area. How far they modified the form of the island, or added to its height is a fair subject of speculation; and whether the steep dip of the lavas seen in the ravines intersecting the slopes of the mountain, *f h*, and *e g*, can be ascribed to such movements. The lavas of more modern date, near Funchal, may be imagined to remain comparatively horizontal, because they have escaped the influence of disturbing forces to which the older nucleus was exposed. Without discussing this point (so fully treated of in reference to Palma), I may observe that unquestionably different parts of Madeira have been formed in succession. Near Porto da Cruz, for example, on the northern coast, trachytes of a grey, and trachytic tuffs almost of a white colour, in slightly inclined or almost horizontal beds, have partially filled up deep valleys previously excavated through the older and inclined basaltic rocks (dipping at an angle of 10° to the north), under which the leaf-bed and lignite before mentioned, fig. 653., p. 517., lie buried. During the convulsions which accompanied the outpouring of every newer series of lavas the older rocks may have been more or less disturbed and tilted, without destroying the general form of the old dome-shaped mountain supposed by us to have been the result of repeated eruptions from the central vents.

The locality just referred to of Porto da Cruz exemplifies, not only the long intervals of time which separated the outflowing of distinct sets of lavas, but also the precedence of the basaltic to the trachytic outpourings. So also on the northern slope of Madeira, I observed between the Jardim and Pico Bodes, situated in a direct line about six miles north-west of Funchal, a well-marked series of trachytic rocks of considerable thickness occupying the highest geological position. They consist of white and grey trachytes, occurring at points varying from 2500 to 3500 feet above the sea. Their position may be understood by supposing them to constitute the uppermost beds represented at *h* in the section, fig. 653., p. 517., and on the slope above *h*. The doctrine, therefore, that in each series of volcanic eruptions the trachytic lavas flow out first, and after them the basaltic kinds (see p. 526.), is by no means borne out in Madeira, although some of the newest currents, like those at the foot of the cones M, N, O, fig. 653., are basaltic.

I may here allude to another feature in the mineralogical structure of Madeira, namely, that most commonly the uppermost of all the volcanic rocks, when we ascend to heights of 1200 feet or more above the sea, consist of compact felspathic trap, with much olivine, separating into spheroidal masses several feet in diameter, especially when some of the contained iron has become more highly oxidated in the atmosphere. M. Delesse, after examining my specimens, informs me that in France they would call this rock basalt, although it is often without augite and simply a mixture of blackish green felspar with olivine. Whatever name we assign to it, the superficial envelope of the island, not only in the line of section followed in fig. 653., p. 517., but also very generally, may be said to consist of this trap, except near the sea, where basalts occur which have not the same spheroidal structure.

Among other indications of a considerable difference of age, even in the superficial volcanic formations of Madeira, I may remark that many of the central peaks, such as A, fig. 653., seem to be the mere skeletons of cones of eruption; whereas the forms of the more modern cones, such as M, N, O, are regular, and have no protruding dikes on their summits or flanks. The newest lavas also in Madeira have, in one district at least, a singularly recent aspect as compared to those of older date, which are decomposed superficially often to the depth of several feet or yards. I allude to the lava currents near Port Moniz, one of which is as rough and bristling as are some streams before alluded to in Palma (p. 512.) of historical date. I am indebted to Mr. Hartung for the annexed drawing of a lava at Port Moniz, which I did not visit myself.

Fig. 656.



Surface of lava near Port Moniz, N.W. point of Madeira; from a drawing by M. Hartung
a. Channel traversing the lava.

It is traversed by a channel, *a*, like one of those already described, p. 507. For how long a period such characters may be retained is uncertain, so much does this depend on the mineral composition of the rock. Some of the lavas of Auvergne of prehistorical date and certainly of high antiquity, are almost as rugged; so that this freshness of aspect is only a probable indication of a relatively modern origin.

CHAPTER XXX.

ON THE DIFFERENT AGES OF THE VOLCANIC ROCKS.

Tests of relative age of volcanic rocks — Tests by superposition and intrusion — Dike of Quarrington Hill, Durham — Test by alteration of rocks in contact — Test by organic remains — Test of age by mineral character — Test by included fragments — Volcanic rocks of the Post-Pliocene period — Basalt of the Bay of Trezza in Sicily—Post-Pliocene volcanic rocks near Naples—Dikes of Somma — Igneous formations of the Newer Pliocene period — Val di Noto in Sicily.

Having referred the sedimentary strata to a long succession of geological periods, we have now to consider how far the volcanic formations can be classed in a similar chronological order. The tests of relative age in this class of rocks are four: — 1st, superposition and intrusion, with or without alteration of the rocks in contact; 2nd, organic remains; 3rd, mineral characters; 4th, included fragments of older rocks.

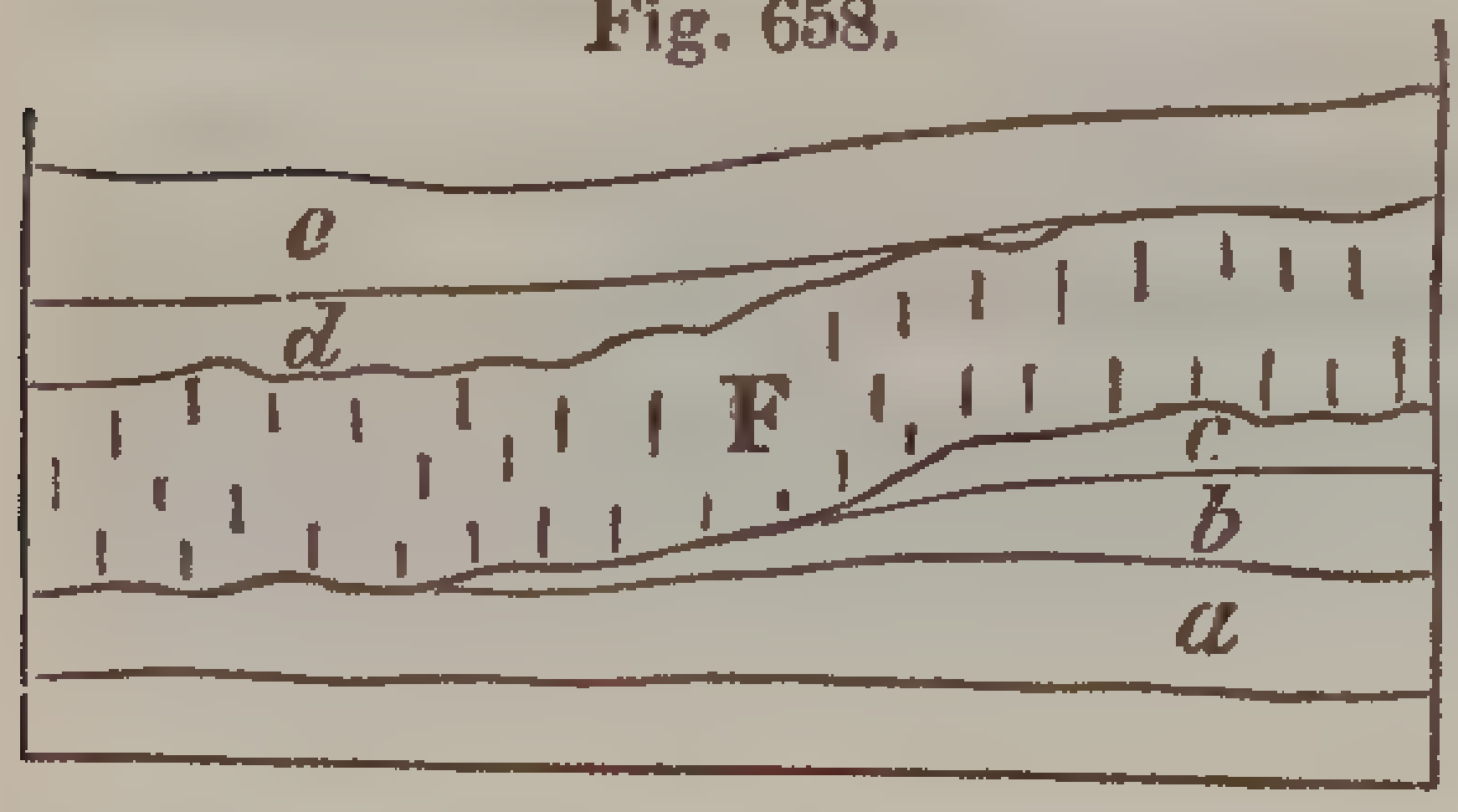
Tests by superposition, &c. — If a volcanic rock rest upon an aqueous deposit, the former must be the newest of the two, but the like rule does not hold good where the aqueous formation rests upon the volcanic, for melted matter, rising from below, may penetrate a sedimentary mass without reaching the surface, or may be forced in conformably between two strata, as *b* at D in the annexed figure (fig. 656.), after which it may cool down and consolidate. Superposition, therefore, is not of the same value as a test of age in the unstratified volcanic rocks as in fossiliferous formations. We can only rely implicitly on this test where the volcanic rocks are contemporaneous, not where they are intrusive. Now, they are said to be contemporaneous if produced by volcanic action which was going on simultaneously with the deposition of the strata with which they are associated. Thus in the section at D (fig. 656.), we may perhaps ascertain that the trap *b* flowed over the fossiliferous bed *c*, and that, after its consolidation, *a* was deposited upon it, *a* and *c* both belonging to the same geological period. But if the stratum *a* be altered by *b* at the point of contact, we must then conclude the trap to have been intrusive, or if, in pursuing *b* for

Fig. 657.

some distance, we find at length that it cuts through the stratum *a*, and then overlies it as at E.

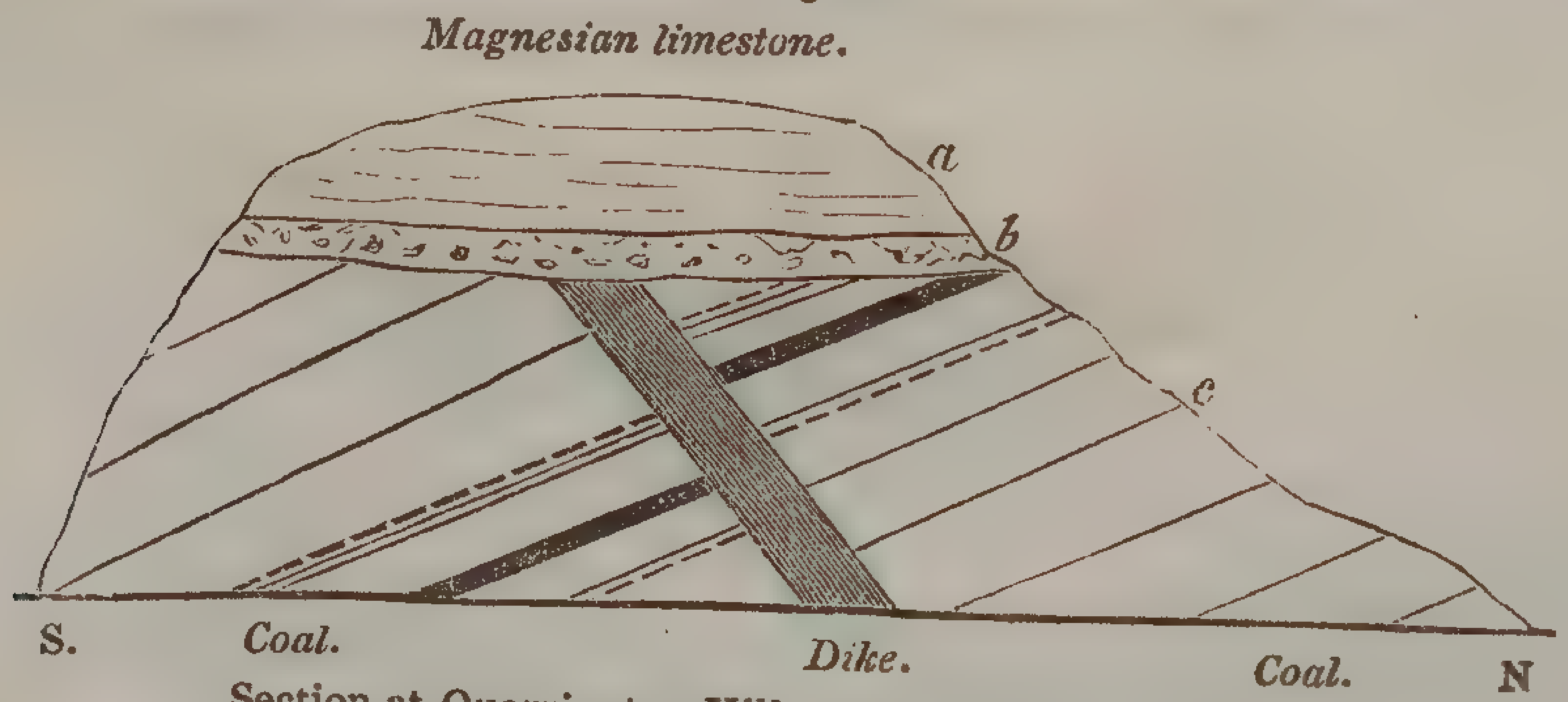
We may, however, be easily deceived in supposing a volcanic rock to be intrusive, when in reality it is contemporaneous; for a sheet of lava, as it spreads over the bottom of the sea, cannot rest every where upon the same stratum, either because these have been denuded, or because, if newly thrown down, they thin out in certain places, thus allowing the lava to cross their edges. Besides the heavy igneous fluid will often, as it moves along, cut a channel into beds of soft mud and sand. Suppose the submarine lava F, fig. 658., to have come in contact in this manner with the strata *a*, *b*, *c*, and that after its consolidation the strata *d*, *e*, are thrown down in a nearly horizontal position, yet so as to lie unconformably to F, the appearance of subsequent intrusion will here be complete, although the trap is in fact contemporaneous. We must not, therefore, hastily, infer that the rock F is intrusive, unless we find the strata *d*, *e*, or *c*, to have been altered at their junction, as if by heat.

Fig. 658.



When trap dikes were described in the preceding chapter, they were shown to be more modern than all the strata which they traverse. A basaltic dike at Quarrington Hill near Durham, passes through coal-measures, the strata of which are inclined, and shifted so that those on the north side of the dike are 24 feet above the level of the corresponding beds on the south side (see section, fig. 659.). But the horizontal beds of overlying Red Sandstone and Magnesian Limestone are not cut through by the dike. Now here the coal-measures were not only deposited, but had subsequently been disturbed, fissured, and shifted, before the fluid trap now forming the dike was introduced into a rent. It is also clear that some of the upper edges of the coal strata, together with the upper part of the dike, had been subsequently removed by denudation before the lower New Red Sandstone and Magnesian Limestone were superimposed. Even in this case, however, although the date

Fig. 659.



Section at Quarrington Hill, east of Durham. (Sedgwick.)
a. Magnesian Limestone (Permian). *b.* Lower New Red Sandstone. *c.* Coal strata.

of the volcanic eruption is brought within narrow limits, it cannot be defined with precision; it may have happened either at the close of the Carboniferous period, or early in that of the Lower New Red Sandstone, or between these two periods, when the state of the animate creation and the physical geography of Europe were gradually changing from the type of the Carboniferous era to that of the Permian.

The test of age by superposition is strictly applicable to all stratified volcanic tuffs, according to the rules already explained in the case of other sedimentary deposits. (See p. 97.)

Test of age by organic remains. — We have seen how, in the vicinity of active volcanos, scoriæ, pumice, fine sand, and fragments of rock are thrown up into the air, and then showered down upon the land, or into neighbouring lakes or seas. In the tuffs so formed shells, corals, or any other durable organic bodies which may happen to be strewed over the bottom of a lake or sea will be embedded, and thus continue as permanent memorials of the geological period when the volcanic eruption occurred. Tufaceous strata thus formed in the neighbourhood of Vesuvius, Etna, Stromboli, and other volcanos now active in islands or near the sea, may give information of the relative age of these tuffs at some remote future period when the fires of these mountains are extinguished. By evidence of this kind we can establish a coincidence in age between volcanic rocks and the different primary, secondary, and tertiary fossiliferous strata.

The tuffs alluded to may not always be marine, but may include, in some places, freshwater shells; in others, the bones of terrestrial quadrupeds. The diversity of organic remains in formations of this nature is perfectly intelligible, if we reflect on the wide dispersion of ejected matter during late eruptions, such as that of the volcano of Coseguina, in the province of Nicaragua, January 19. 1835. Hot cinders and fine scoriæ were then cast up to a vast height, and covered the ground as they fell to the depth of more than 10 feet, and for a distance of 8 leagues from the crater in a southerly direction. Birds, cattle, and wild animals were scorched to death in great numbers, and buried in ashes. Some volcanic dust fell at Chiapa, upwards of 1200 miles, not to leeward of the volcano as might have been anticipated, but to windward, a striking proof of a counter current in the upper region of the atmosphere; and some on Jamaica, about 700 miles distant to the north-east. In the sea, also, at the distance of 1100 miles from the point of eruption, Captain Eden of the Conway sailed 40 miles through floating pumice, among which were some pieces of considerable size.*

Test of age by mineral composition. — As sediment of homogeneous composition, when discharged from the mouth of a large river, is often deposited simultaneously over a wide space, so a particular kind of lava, flowing from a crater during one eruption, may spread over an extensive area; as in Iceland in 1783, when the

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* Caldcleugh, Phil. Trans. 1836. p. 27.

melted matter, pouring from Skaptar Jokul, flowed in streams in opposite directions, and caused a continuous mass the extreme points of which were 90 miles distant from each other. This enormous current of lava varied in thickness from 100 feet to 600 feet, and in breadth from that of a narrow river gorge to 15 miles.* Now, if such a mass should afterwards be divided into separate fragments by denudation, we might still perhaps identify the detached portions by their similarity in mineral composition. Nevertheless, this test will not always avail the geologist; for, although there is usually a prevailing character in lava emitted during the same eruption, and even in the successive currents flowing from the same volcano, still, in many cases, the different parts even of one lava-stream, or, as before stated, of one continuous mass of trap, vary much in mineral composition and texture.

In Auvergne, the Eifel, and other countries where trachyte and basalt are both present, the trachytic rocks are for the most part older than the basaltic. These rocks do, indeed, sometimes alternate partially, as in the volcano of Mont Dor, in Auvergne; and we have seen that in Madeira trachytic rocks may overlie an older basaltic series (p. 521.); but the great mass of trachyte occupies more generally perhaps an inferior position, and is cut through and overflowed by basalt. It can by no means be inferred that trachyte predominated at one period of the earth's history and basalt at another, for we know that trachytic lavas have been formed at many successive periods, and are still emitted from many active craters; but it seems that in each region, where a long series of eruptions have occurred, the more felspathic lavas have been first emitted, and the escape of the more augitic kinds has followed. The hypothesis suggested by Mr. Scrope may, perhaps, afford a solution of this problem. The minerals, he observes, which abound in basalt are of greater specific gravity than those composing the felspathic lavas; thus, for example, hornblende, augite, and olivine are each more than three times the weight of water; whereas common felspar, albite, and Labrador felspar have each scarcely more than 2½ times the specific gravity of water; and the difference is increased in consequence of there being much more iron in a metallic state in basalt and greenstone than in trachyte and other felspathic lavas and trap rocks. If, therefore, a large quantity of rock be melted up in the bowels of the earth by volcanic heat, the denser ingredients of the boiling fluid may sink to the bottom, and the lighter remaining above would in that case be first propelled upwards to the surface by the expansive power of gases. Those materials, therefore, which occupy the lowest place in the subterranean reservoir will always be emitted last, and take the uppermost place on the exterior of the earth's crust.

Test by included fragments. — We may sometimes discover the relative age of two trap rocks, or of an aqueous deposit and the trap on which it rests, by finding fragments of one included in the other,

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* See Principles, *Index*, "Skaptar Jokul."

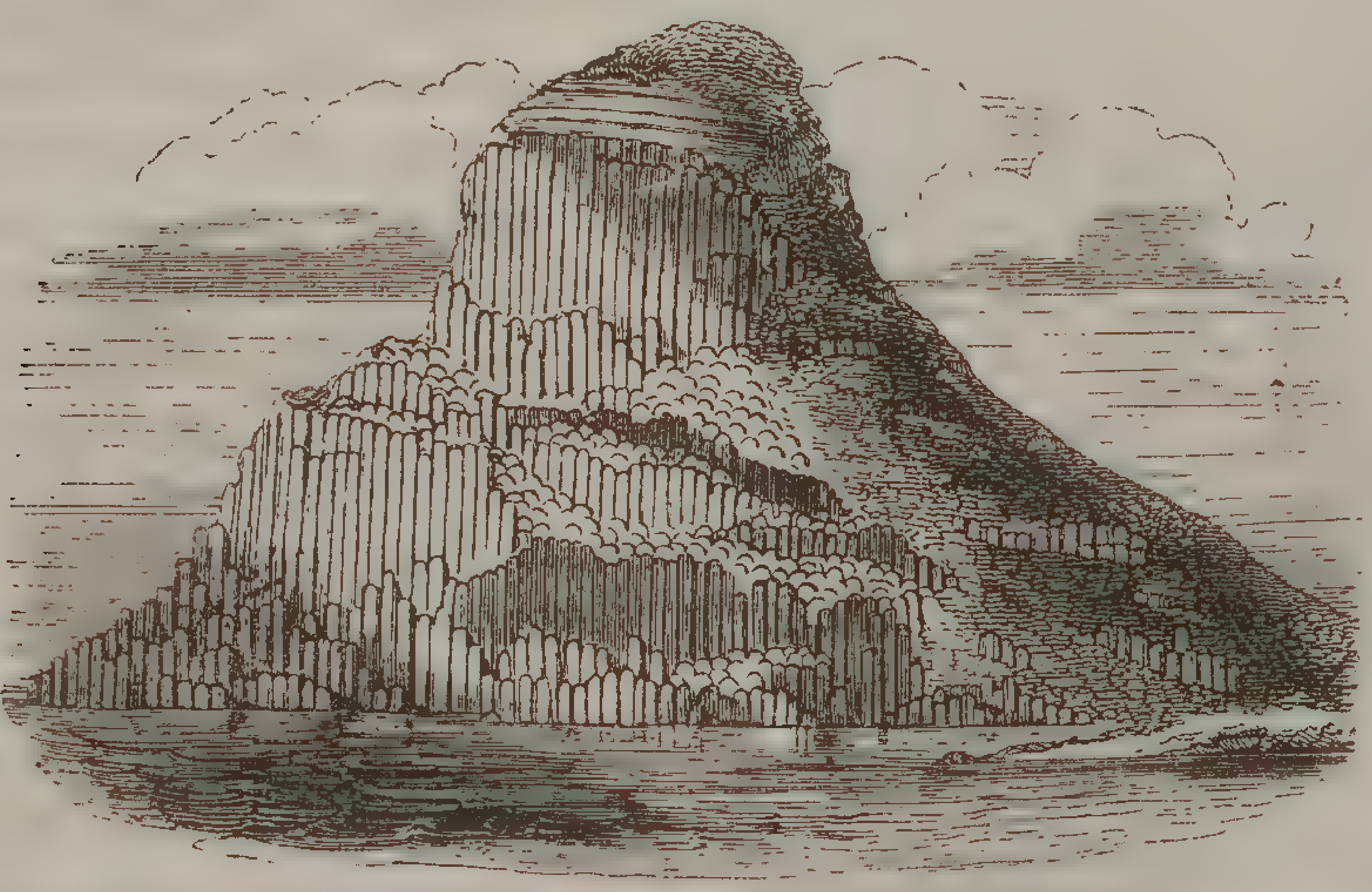
in cases such as those before alluded to, where the evidence of superposition alone would be insufficient. It is also not uncommon to find a conglomerate almost exclusively composed of rolled pebbles of trap, associated with some fossiliferous stratified formation in the neighbourhood of massive trap. If the pebbles agree generally in mineral character with the latter, we are then enabled to determine its relative age by knowing that of the fossiliferous strata associated with the conglomerate. The origin of such conglomerates is explained by observing the shingle beaches composed of trap pebbles in modern volcanic islands, or at the base of Etna.

Post-Pliocene Period (*including the Recent*). — I shall now select examples of contemporaneous volcanic rocks of successive geological periods, to show that igneous causes have been in activity in all past ages of the world, and that they have been ever shifting the places where they have broken out at the earth's surface.

One portion of the lavas, tuffs, and trap-dikes of Etna, Vesuvius, and the Island of Ischia has been produced within the historical era; another, and a far more considerable part, originated at times immediately antecedent, when the waters of the Mediterranean were already inhabited by the existing species of testacea. The southern and eastern flanks of Etna are skirted by a fringe of alternating sedimentary and volcanic deposits, of submarine origin, as at Adernò, Trezza, and other places. Of sixty-five species of fossil shells which I procured in 1828 from this formation, near Trezza, it was impossible to distinguish any one from species now living in the neighbouring sea.

The Cyclopian Islands, called by the Sicilians Dei Faraglioni, in the sea-cliffs of which these beds of clay, tuff, and associated lava are laid open to view, are situated in the Bay of Trezza, and may be regarded as the extremity of a promontory severed from the main land. Here numerous proofs are seen of submarine eruptions, by which the

Fig. 660.



View of the Isle of Cyclops in the Bay of Trezza.*

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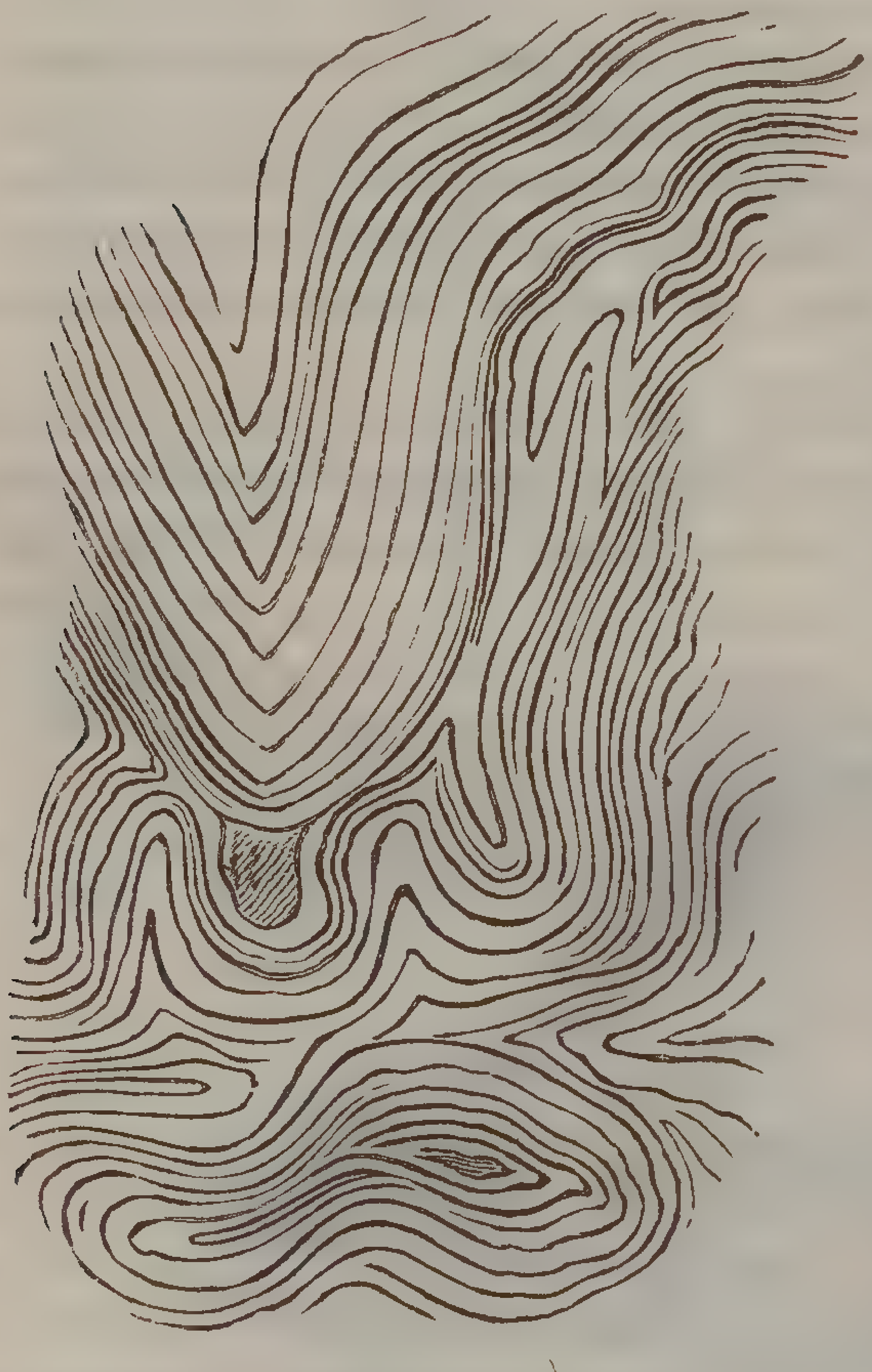
* This view of the Isle of Cyclops is from an original drawing by my friend the late Captain Basil Hall, R.N.

argillaceous and sandy strata were invaded and cut through, and tufaceous breccias formed. Inclosed in these breccias are many angular and hardened fragments of laminated clay in different states of alteration by heat, and intermixed with volcanic sands.

The loftiest of the Cyclopian islets, or rather rocks, is about 200 feet in height, the summit being formed of a mass of stratified clay, the laminæ of which are occasionally subdivided by thin arenaceous layers. These strata dip to the N.W., and rest on a mass of columnar lava (see fig. 660.) in which the tops of the pillars are weathered, and so rounded as to be often hemispherical. In some places in the adjoining and largest islet of the group, which lies to the north-eastward of that represented in the drawing (fig. 660.), the overlying clay has been greatly altered and hardened by the igneous rock, and occasionally contorted in the most extraordinary manner; yet the lamination has not been obliterated, but, on the contrary, rendered much more conspicuous, by the indurating process.

In the annexed woodcut (fig. 661.) I have represented a portion of the altered rock, a few feet square, where the alternating thin laminæ of sand and clay have put on the appearance which we often observe in some of the most contorted of the metamorphic schists.

Fig. 661.



Contortions of strata in the largest of the Cyclopian Islands.

A great fissure, running from east to west, nearly divides this larger island into two parts, and lays open its internal structure. In the section thus exhibited, a dike of lava is seen, first cutting through an older mass of lava, and then penetrating the superincumbent tertiary strata. In one place the lava ramifies and terminates in thin veins, from a few feet to a few inches in thickness. (See fig. 662.).

The arenaceous laminæ are much hardened at the point of contact, and the clays are converted into siliceous schist. In this island the altered rocks assume a honeycombed structure on their weathered surface, singularly contrasted with the smooth and even outline which the same beds present in their usual soft and yielding state.

The pores of the lava are sometimes coated, or entirely filled, with carbonate of lime, and with a zeolite resembling analcime, which has

Fig. 662.

Post-Pliocene strata invaded by lava, Isle of Cyclops (horizontal section).

a. Lava. *b.* Laminated clay and sand. *c.* The same altered.

been called cyclopite. The latter mineral has also been found in small fissures traversing the altered marl, showing that the same cause which introduced the minerals into the cavities of the lava, whether we suppose sublimation or aqueous infiltration, conveyed it also into the open rents of the contiguous sedimentary strata.

Post-Pliocene formations near Naples.—I have traced in the "Principles of Geology" the history of the changes which the volcanic region of Campania is known to have undergone during the last 2000 years. The aggregate effect of igneous operations during that period is far from insignificant, comprising as it does the formation of the modern cone of Vesuvius since the year 79, and the production of several minor cones in Ischia, together with that of Monte Nuovo in the year 1538. Lava-currents have also flowed upon the land and along the bottom of the sea—volcanic sand, pumice, and scoriæ have been showered down so abundantly that whole cities were buried—tracts of the sea have been filled up or converted into shoals—and tufaceous sediment has been transported by rivers and land-floods to the sea. There are also proofs, during the same recent period, of a permanent alteration of the relative levels of the land and sea in several places, and of the same tract having, near Puzzuoli, been alternately upheaved and depressed to the amount of more than 20 feet. In connection with these convulsions, there are found, on the shores of the Bay of Baiæ, recent tufaceous strata, filled with articles fabricated by the hands of man, and mingled with marine shells.

It was also stated in this work (p. 119.), that when we examine this same region, it is found to consist largely of tufaceous strata, of a date anterior to human history or tradition, which are of such thickness as to constitute hills from 500 to more than 2000 feet in height. These post-pliocene strata, containing recent marine shells, alternate with distinct currents and sheets of lava which were of contemporaneous origin; and we find that in Vesuvius itself, the ancient cone called Somma is of far greater volume than the modern cone, and is intersected by a far greater number of dikes. In contrasting this ancient part of the mountain with that of modern date, one principal point of difference is observed; namely, the greater frequency in the older cone of fragments of altered sedimentary rocks ejected during eruptions. We may easily conceive that the first explosions would act with the greatest violence, rending and shattering whatever solid masses obstructed the escape of lava and the accompanying gases, so that great heaps of ejected pieces of rock would naturally occur in the tufaceous breccias formed by the earliest eruptions. But when a passage had once been opened, and an habitual vent established, the materials thrown out would consist of liquid lava, which would take the form of sand and scoriæ, or of angular fragments of such solid lavas as may have choked up the vent.

Among the fragments which abound in the tufaceous breccias of Somma, none are more common than a saccharoid dolomite, supposed to have been derived from an ordinary limestone altered by heat and volcanic vapours.

Carbonate of lime enters into the composition of so many of the simple minerals found in Somma, that M. Mitscherlich, with much probability, ascribes their great variety to the action of the volcanic heat on subjacent masses of limestone.

Dikes of Somma. — The dikes seen in the great escarpment which Somma presents towards the modern cone of Vesuvius are very numerous. They are for the most part vertical, and traverse at right angles the beds of lava, scoriæ, volcanic breccia, and sand, of which the ancient cone is composed. They project in relief several inches or sometimes feet, from the face of the cliff, being extremely compact, and less destructible than the intersected tuffs and porous lavas. In vertical extent they vary from a few yards to 500 feet, and in breadth from 1 to 12 feet. Many of them cut all the inclined beds in the escarpment of Somma from top to bottom, others stop short before they ascend above half way, and a few terminate at both ends, either in a point or abruptly. In mineral composition they scarcely differ from the lavas of Somma, the rock consisting of a base of leucite and augite, through which large crystals of augite and some of leucite are scattered.* Examples are not rare of one dike cutting through another, and in one instance a shift or fault is seen at the point of intersection.

In some cases, however, the rents seem to have been filled laterally, when the walls of the crater had been broken by star-shaped cracks, as seen in the accompanying wood-cut (fig. 663.). But the shape of

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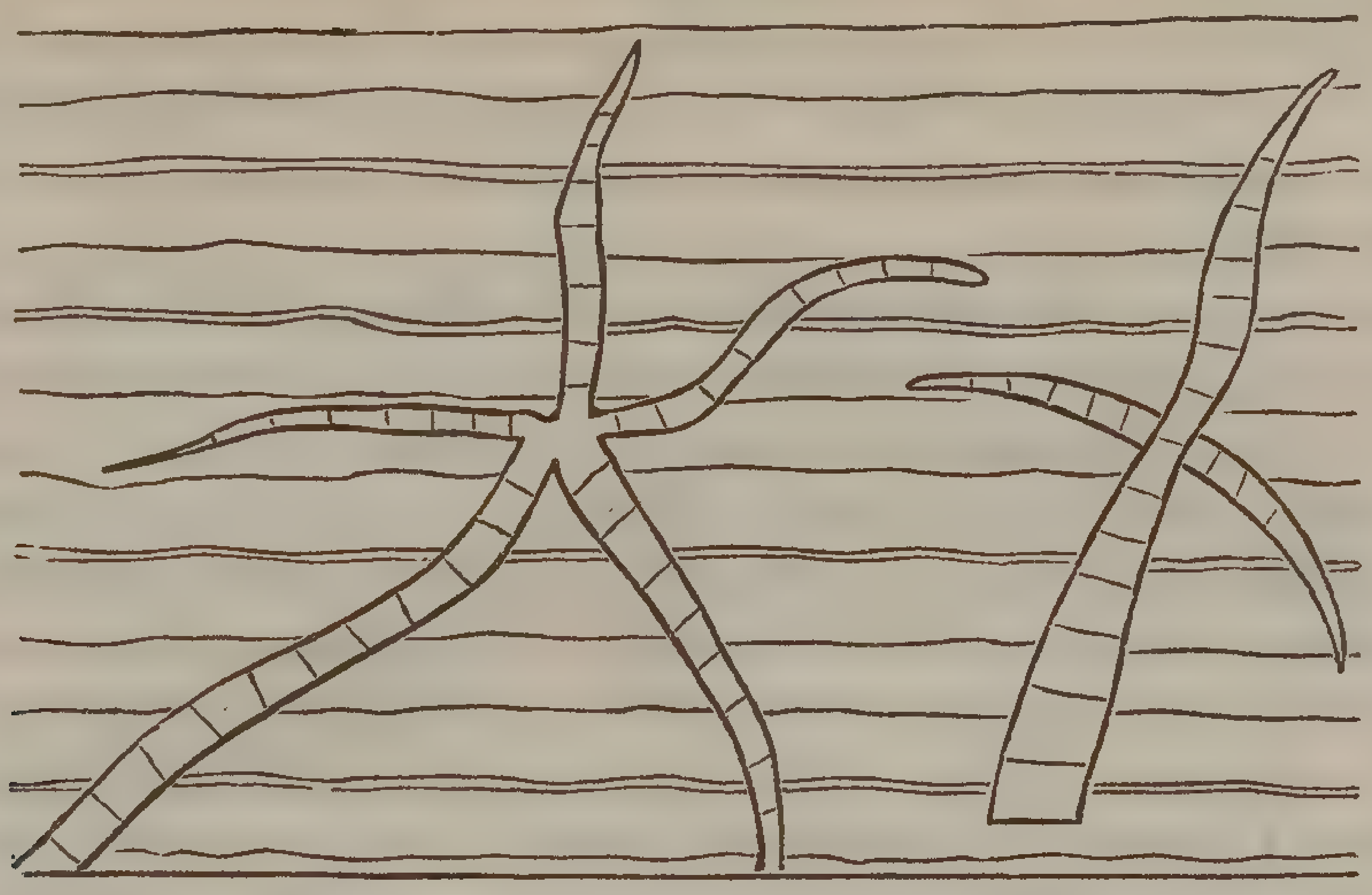
* L. A. Necker, Mém. de la Soc. de Phys. et d'Hist. Nat. de Génève, tom. ii. part i. Nov. 1822.

Fig. 663.



Dikes or veins at the Punto del Nasone on Somma. (Necker.*)

these rents is an exception to the general rule; for nothing is more remarkable than the usual parallelism of the opposite sides of the dikes, which correspond almost as regularly as the two opposite faces of a wall of masonry. This character appears at first the more inexplicable, when we consider how jagged and uneven are the rents caused by earthquakes in masses of heterogeneous composition, like those composing the cone of Somma. In explanation of this phenomenon, M. Necker refers us to Sir W. Hamilton's account of an eruption of Vesuvius in the year 1779, who records the following facts: — "The lavas, when they either boiled over the crater, or broke out from the conical parts of the volcano, constantly formed channels as regular as if they had been cut by art down the steep part of the mountain; and, whilst in a state of perfect fusion, continued their course in those channels, which were sometimes full to the brim, and at other times more or less so, according to the quantity of matter in motion.

These channels, upon examination after an eruption, I have found to be in general from two to five or six feet wide, and seven or eight feet deep. They were often hid from the sight by a quantity of scoriæ that had formed a crust over them; and the lava, having been conveyed in a covered way for some yards, came out fresh again into an open channel. After an eruption, I have walked in some of those subterraneous or covered galleries, which were exceedingly curious, the sides, top, and bottom *being worn perfectly smooth and even* in most parts, by the violence of the currents of the red-hot lavas which they had conveyed for many weeks successively."†

Now, the walls of a vertical fissure, through which lava has ascended in its way to a volcanic vent, must have been exposed to the same erosion as the sides of the channels before adverted to.

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* From a drawing of M. Necker, in Mém. above cited.

† Phil. Trans., vol. lxx., 1780.

The prolonged and uniform friction of the heavy fluid, as it is forced and made to flow upwards, cannot fail to wear and smooth down the surfaces on which it rubs, and the intense heat must melt all such masses as project and obstruct the passage of the incandescent fluid.

The texture of the Vesuvian dikes is different at the edges and in the middle. Towards the centre, observes M. Necker, the rock is larger grained, the component elements being in a far more crystalline state; while at the edge the lava is sometimes vitreous, and always finer grained. A thin parting band, approaching in its character to pitchstone, occasionally intervenes, at the contact of the vertical dike and intersected beds. M. Necker mentions one of these at the place called Primo Monte, in the Atrio del Cavallo; and when I examined Somma, in 1828, I saw three or four others in different parts of the great escarpment. These phenomena are in perfect harmony with the results of the experiments of Sir James Hall and Mr. Gregory Watt, which have shown that a glassy texture is the effect of sudden cooling, while, on the contrary, a crystalline grain is produced where fused minerals are allowed to consolidate slowly and tranquilly under high pressure.

It is evident that the central portion of the lava in a fissure would, during consolidation, part with its heat more slowly than the sides, although the contrast of circumstances would not be so great as when we compare the lava near the bottom and at the surface of a current flowing in the open air. In this case the uppermost part, where it has been in contact with the atmosphere, and where refrigeration has been most rapid, is always found to consist of scoriform, vitreous, and porous lava; while at a greater depth the mass assumes a more lithoidal structure, and then becomes more and more stony as we descend, until at length we are able to recognize with a magnifying glass the simple minerals of which the rock is composed. On penetrating still deeper, we can detect the constituent parts by the naked eye, and in the Vesuvian currents distinct crystals of augite and leucite become apparent.

The same phenomenon, observes M. Necker, may readily be exhibited on a smaller scale, if we detach a piece of liquid lava from a moving current. The fragment cools instantly, and we find the surface covered with a vitreous coat; while the interior, although extremely fine-grained, has a more stony appearance.

It must, however, be observed, that although the lateral portions of the dikes are finer grained than the central, yet the vitreous parting layer before alluded to is rare in Vesuvius. This may, perhaps, be accounted for, as the above-mentioned author suggests, by the great heat which the walls of a fissure may acquire before the fluid mass begins to consolidate, in which case the lava, even at the sides, would cool very slowly. Some fissures, also, may be filled from above, as frequently happens in the volcanos of the Sandwich Islands, according to the observations of Mr. Dana; and in this case the refrigeration at the sides would be more rapid than when the melted matter flowed upwards from the volcanic foci, in an intensely heated state. Mr. Darwin informs me that in St. Helena almost every dike has a vitreous selvage.

The rock composing the dikes both in the modern and ancient part of Vesuvius is far more compact than that of ordinary lava, for the pressure of a column of melted matter in a fissure greatly exceeds that in an ordinary stream of lava; and pressure checks the expansion of those gases which give rise to vesicles in lava.

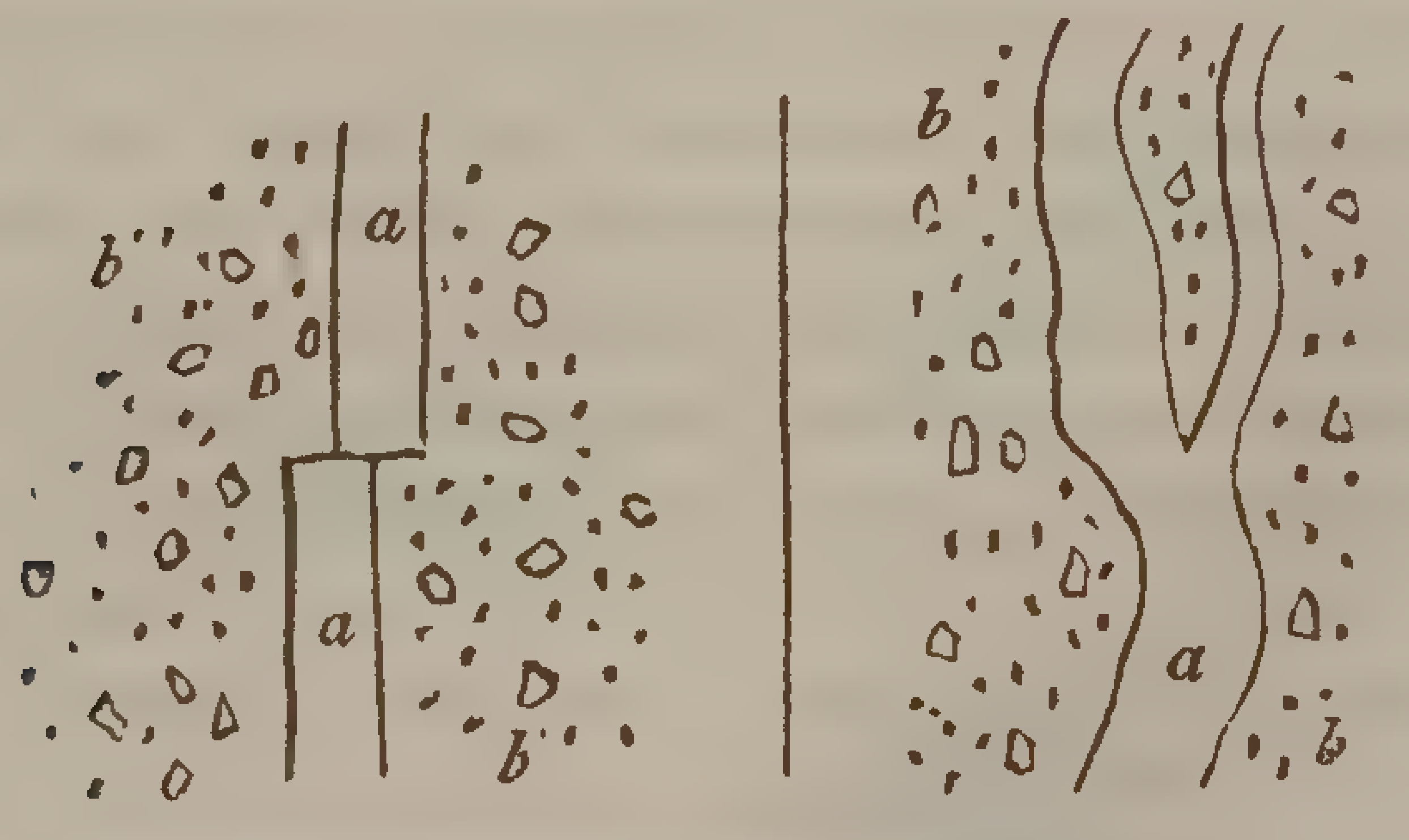
There is a tendency in almost all the Vesuvian dikes to divide into horizontal prisms, a phenomenon in accordance with the formation of vertical columns in horizontal beds of lava; for in both cases the divisions which give rise to the prismatic structure are at right angles to the cooling surfaces.

Newer Pliocene Period — Val di Noto. — I have already alluded (see p. 157.) to the igneous rocks which are associated with a great marine formation of limestone, sand, and marl in the southern part of Sicily, as at Vizzini and other places. In this formation, which was shown to belong to the Newer Pliocene period, large beds of oysters and corals repose upon lava, and are unaltered at the point of contact. In other places we find dikes of igneous rock intersecting the fossiliferous beds, and converting the clays into siliceous schist, the laminæ being contorted and shivered into innumerable fragments at the junction, as near the town of Vizzini.

The volcanic formations of the Val di Noto usually consist of the most ordinary variety of basalt, with or without olivine. The rock is sometimes compact, often very vesicular. The vesicles are occasionally empty, both in dikes and currents, and are in some localities filled with calcareous spar, arragonite, and zeolites. The structure is, in some places, spheroidal; in others, though rarely, columnar. I found dikes of amygdaloid, wacké, and prismatic basalt, intersecting the limestone at the bottom of the hollow called Gozzo degli Martiri, below Melilli.

Dikes. — Dikes of vesicular and amygdaloidal lava are also seen traversing marine tuff or peperino, west of Palagonia, some of the pores of the lava being empty, while others are filled with carbonate

Fig. 664. Fig. 665.



Ground-plan of dikes near Palagonia.

a. Lava.
b. Peperino, consisting of volcanic sand, mixed with fragments of lava and limestone.

of lime. In such cases we may suppose the peperino to have resulted from showers of volcanic sand and scoriæ, together with fragments of limestone, thrown out by a submarine explosion, similar to that which gave rise to Graham Island in 1831. When the mass was, to a certain degree, consolidated, it may have been rent open, so that the lava ascended through fissures, the walls of which were perfectly even and parallel. After the melted matter that filled the rent in fig. 664. had cooled down, it must have been fractured and shifted horizontally by a lateral movement.

In the second figure (fig. 665.), the lava has more the appearance of a vein which forced its way through the peperino. It is highly probable that similar appearances would be seen, if we could examine the floor of the sea in that part of the Mediterranean where the waves have recently washed away the new volcanic island; for when a superincumbent mass of ejected fragments has been removed by denudation, we may expect to see sections of dikes traversing tuff, or, in other words, sections of the channels of communication by which the subterranean lavas reached the surface.

CHAPTER XXXI.

ON THE DIFFERENT AGES OF THE VOLCANIC ROCKS — *continued.*

Volcanic rocks of the Older Pliocene period — Tuscany — Rome — Volcanic region of Olot in Catalonia — Cones and lava-currents — Ravines and ancient gravel-beds — Jets of air called Bufadors — Age of the Catalonian volcanos — Miocene period — Brown-coal of the Eifel and contemporaneous trachytic breccias — Age of the brown-coal — Peculiar characters of the volcanos of the upper and lower Eifel — Lake Craters — Trass — Hungarian volcanos.

Older Pliocene period — Italy. — IN Tuscany, as at Radicofani, Viterbo, and Aquapendente, and in the Campagna di Roma, submarine volcanic tuffs are interstratified with the Older Pliocene strata of the Subapennine hills in such a manner as to leave no doubt that they were the products of eruptions which occurred when the shelly marls and sands of the Subapennine hills were in the course of deposition. This opinion I expressed * after my visit to Italy in 1828, and it has recently (1850) been confirmed by the arguments adduced by Sir R. Murchison in favour of the submarine origin of the earlier volcanic rocks of Italy.† These rocks are well known to rest conformably on the Subapennine marls, even as far south as Monte Mario in the suburbs of Rome. On the exact age of the deposits of Monte Mario new light has recently been thrown by a careful study of their marine fossil shells, undertaken by MM. Rayneval, Vanden Hecke, and Ponza. They have compared no less than 160 species ‡ with the shells of the Coralline Crag of Suffolk, so well described by Mr. Searles Wood; and the specific agreement between the British and Italian fossils is so great, if we make due allowance for geographical distance and the difference of latitude, that we can have little hesitation in referring both to the same period or to the Older Pliocene of this work. It is highly probable that, between the oldest trachytes of Tuscany and the newest rocks in the neighbourhood of Naples, a series of volcanic products might be detected of every age from the Older Pliocene to the historical epoch.

Catalonia. — Geologists are far from being able, as yet, to assign to each of the volcanic groups scattered over Europe a precise chronological place in the tertiary series; but I shall describe here,

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* See 1st edit. of Principles of Geology, vol. iii. chaps. xiii. and xiv., 1833; and former edits. of this work, ch. xxxi.

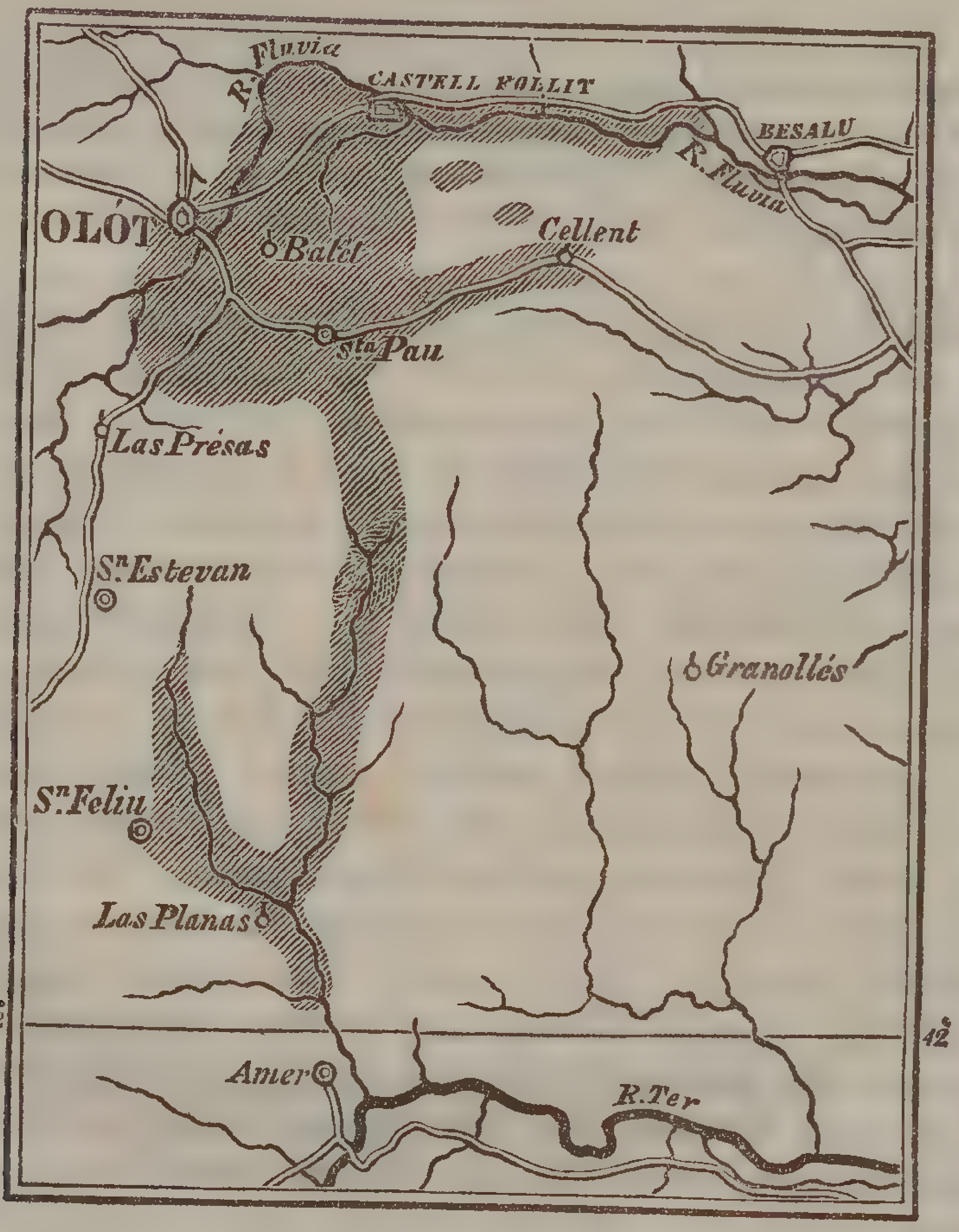
† Geol. Quart. Journ. vol. vi. p. 281.

‡ Catalogue des Fossiles de Monte Mario, Rome, 1854.

as probably referable to some part of the Pliocene period, a district of extinct volcanos near Olot, in the north of Spain, which is little known, and which I visited in the summer of 1830.

The whole extent of country occupied by volcanic products in Catalonia is not more than fifteen geographical miles from north to south, and about six from east to west. The vents of eruption range entirely within a narrow band running north and south; and the branches, which are represented as extending eastward in the map, are formed simply of two lava-streams — those of Castell Follit and Cellent.

Fig. 666.



Volcanic district of Catalonia.

Dr. Maclure, the American geologist, was the first who made known the existence of these volcanos*; and, according to his description, the volcanic region extended over twenty square leagues, from Amer to Massanet. I searched in vain in the environs of Massanet in the Pyrenees, for traces of a lava-current; and I can say with confidence, that the adjoining map gives a correct view of the true area of the volcanic action.

Geological structure of the district. — The eruptions have burst entirely through fossiliferous rocks, composed in great part of grey

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* Maclure, Journ. de Phys., vol. lxvi. p. 219., 1808; cited by Daubeny, Description of Volcanos, p. 24.

and greenish sandstone and conglomerate, with some thick beds of nummulitic limestone. The conglomerate contains pebbles of quartz, limestone, and Lydian stone. This system of rocks is very extensively spread throughout Catalonia; one of its members being a red sandstone, to which the celebrated salt-rock of Cardona, usually considered as of the cretaceous era, is subordinate.

Near Amer, in the Valley of the Ter, on the southern borders of the region delineated in the map, primary rocks are seen, consisting of gneiss, mica-schist, and clay-slate. They run in a line nearly parallel to the Pyrenees, and throw off the fossiliferous strata from their flanks, causing them to dip to the north and north-west. This dip, which is towards the Pyrenees, is connected with a distinct axis of elevation, and prevails through the whole area described in the map, the inclination of the beds being sometimes at an angle of between 40 and 50 degrees.

It is evident that the physical geography of the country has undergone no material change since the commencement of the era of the volcanic eruptions, except such as has resulted from the introduction of new hills of scoriæ, and currents of lava upon the surface. If the lavas could be remelted and poured out again from their respective craters, they would descend the same valleys in which they are now seen, and re-occupy the spaces which they at present fill. The only difference in the external configuration of the fresh lavas would consist in this, that they would nowhere be intersected by ravines, or exhibit marks of erosion by running water.

Volcanic cones and lavas. — There are about fourteen distinct cones with craters in this part of Spain, besides several points whence lavas may have issued; all of them arranged along a narrow line running north and south, as will be seen in the map. The greatest number of perfect cones are in the immediate neighbourhood of Olot, some of which (Fig. 667., Nos. 2, 3, and 5.) are represented in the annexed woodcut; and the level plain on which that town stands has clearly been produced by the flowing down of many lava-streams from those hills into the bottom of a valley, probably once of considerable depth, like those of the surrounding country.

In this drawing an attempt is made to represent, by the shading of the landscape, the different geological formations of which the country is composed.* The white line of mountains (No. 1.) in the distance is the Pyrenees, which are to the north of the spectator, and consist of hypogene and ancient fossiliferous rocks. In front of these are the fossiliferous formations (No. 4.), which are in shade. Still nearer to us the hills 2, 3, 5, are volcanic cones, and the rest of the ground on which the sunshine falls is strewed over with volcanic ashes and lava.

The Fluvia, which flows near the town of Olot, has cut to the depth of only 40 feet through the lavas of the plain before men-

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* This view is taken from a sketch which I made on the spot in 1830.

Fig. 667.

View of the Volcanos around Olot in Catalonia.

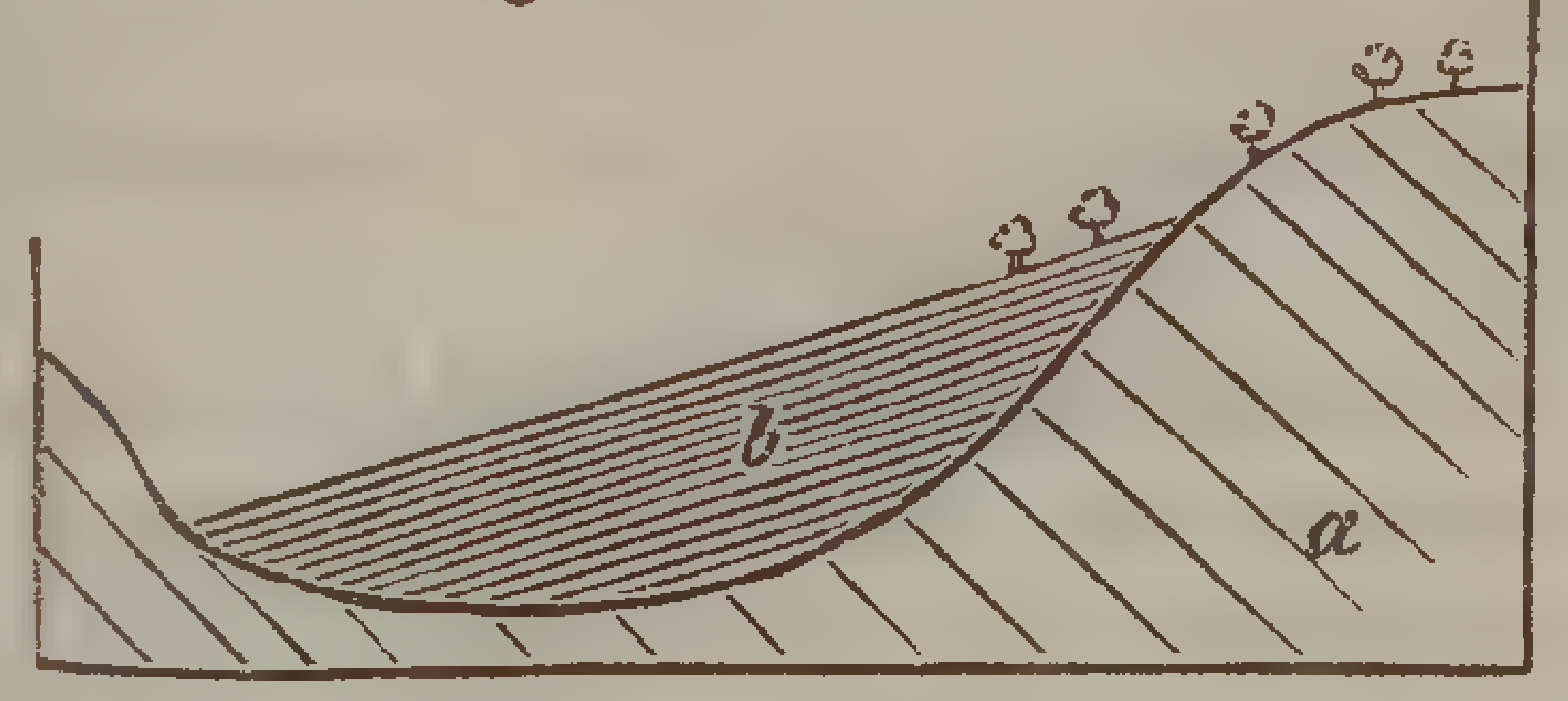
tioned. The bed of the river is hard basalt; and at the bridge of Santa Madalena are seen two distinct lava-currents, one above the other, separated by a horizontal bed of scoriæ 8 feet thick.

In one place, to the south of Olot, the even surface of the plain is broken by a mound of lava, called the "Bosque de Tosca," the upper part of which is scoriaceous, and covered with enormous heaps of fragments of basalt, more or less porous. Between the numerous hummocks thus formed are deep cavities, having the appearance of small craters. The whole precisely resembles some of the modern currents of Etna, or that of Côme, near Clermont; the last of which, like the Bosque de Tosca, supports only a scanty vegetation.

Most of the Catalonian volcanos are as entire as those in the neighbourhood of Naples or on the flanks of Etna. One of these, called Montsacopa (No. 3. fig. 667.), is of a very regular form, and has a circular depression or crater at the summit. It is chiefly made up of red scoriæ, undistinguishable from those of the minor cones of Etna. The neighbouring hills of Olivet (No. 2.) and Garrinada (No. 5.) are of similar composition and shape. The largest crater of the whole district occurs farther to the east of Olot, and is called Santa Margarita. It is 455 feet deep, and about a mile in circumference. Like Astroni, near Naples, it is richly covered with wood, wherein game of various kinds abounds.

Although the volcanos of Catalonia have broken out through sandstone, shale, and limestone, as have those of the Eifel, in Germany, to be described in the sequel, there is a remarkable difference in the nature of the ejections composing the cones in these two regions. In the Eifel, the quantity of pieces of sandstone and shale thrown out from the vents is often so immense as far to exceed in volume the scoriæ, pumice, and lava; but I sought in vain in the cones near Olot for a single fragment of any extraneous rock; and Don Francisco Bolos, an eminent botanist of Olot, informed me that he had never been able to detect any.

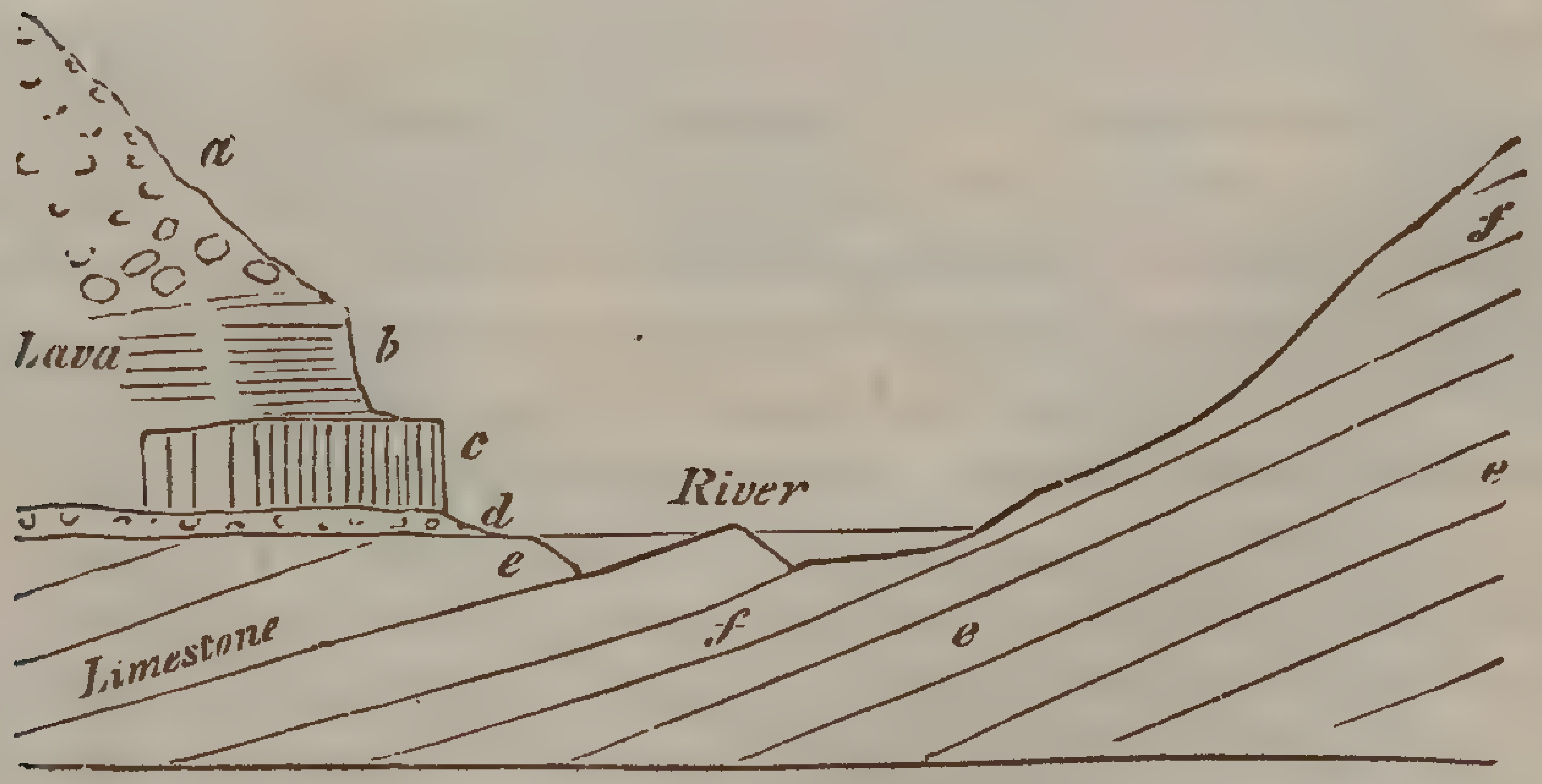
Fig. 668.



a. Conglomerate.
b. Thin seams of volcanic sand and scoriæ.

Volcanic sand and ashes are not confined to the cones, but have been sometimes scattered by the wind over the country, and drifted into narrow valleys, as is seen between Olot and Cellent, where the annexed section (fig. 668.) is exposed. The light cindery volcanic matter rests in thin regular layers, just as it alighted on the slope formed of the solid conglomerate. No flood could have passed through the valley since the scoriæ fell, or these would have been for the most part removed. The currents of lava in Catalonia, like those of Auvergne, the Vivarais, Iceland, and all mountainous countries, are of considerable depth in narrow defiles, but spread out into comparatively thin sheets in places where the valleys widen. If a river has flowed on nearly level ground, as in the great plain near Olot, the water has only excavated a channel of slight depth; but where the declivity is great, the stream has cut a deep section, sometimes by penetrating directly through the central part of a lava-current, but more frequently by passing between the lava and the secondary or tertiary rock which bounds the valley. Thus, in the accompanying section (fig. 669.), at the bridge of Cellent, six miles east of Olot, we see the lava on one side of the small stream; while the inclined stratified rocks constitute the channel and opposite bank. The upper part of the lava at that place, as is usual in the currents of Etna and Vesuvius, is scoriaceous; farther down it becomes less

Fig. 669.



Section above the bridge of Cellent.

a. Scoriaceous lava.
b. Schistose basalt.
c. Columnar basalt.
d. Scoriæ, vegetable soil, and alluvium.
e. Nummulitic limestone.
f. Micaceous grey sandstone.

porous, and assumes a spheroidal structure; still lower it divides in horizontal plates, each about 2 inches in thickness, and is more compact. Lastly, at the bottom is a mass of prismatic basalt about 5 feet thick. The vertical columns often rest immediately on the subjacent stratified rocks; but there is sometimes an intervention of sand and scoriæ such as cover the country during volcanic eruptions, and which, unless protected, as here, by superincumbent lava, is washed away from the surface of the land. Sometimes, the bed *d* contains a few pebbles and angular fragments of rock; in other places fine earth, which may have constituted an ancient vegetable soil.

In several localities, beds of sand and ashes are interposed between the lava and subjacent stratified rock, as may be seen if we follow the course of the lava-current which descends from Las Planas towards Amer, and stops two miles short of that town. The river there has often cut through the lava, and through 18 feet of underlying limestone. Occasionally an alluvium, several feet thick, is interposed between the igneous and marine formations; and it is interesting to remark that in this, as in other beds of pebbles occupying a similar position, there are no rounded fragments of lava; whereas in the most modern gravel-beds of the rivers of this country volcanic pebbles are abundant.

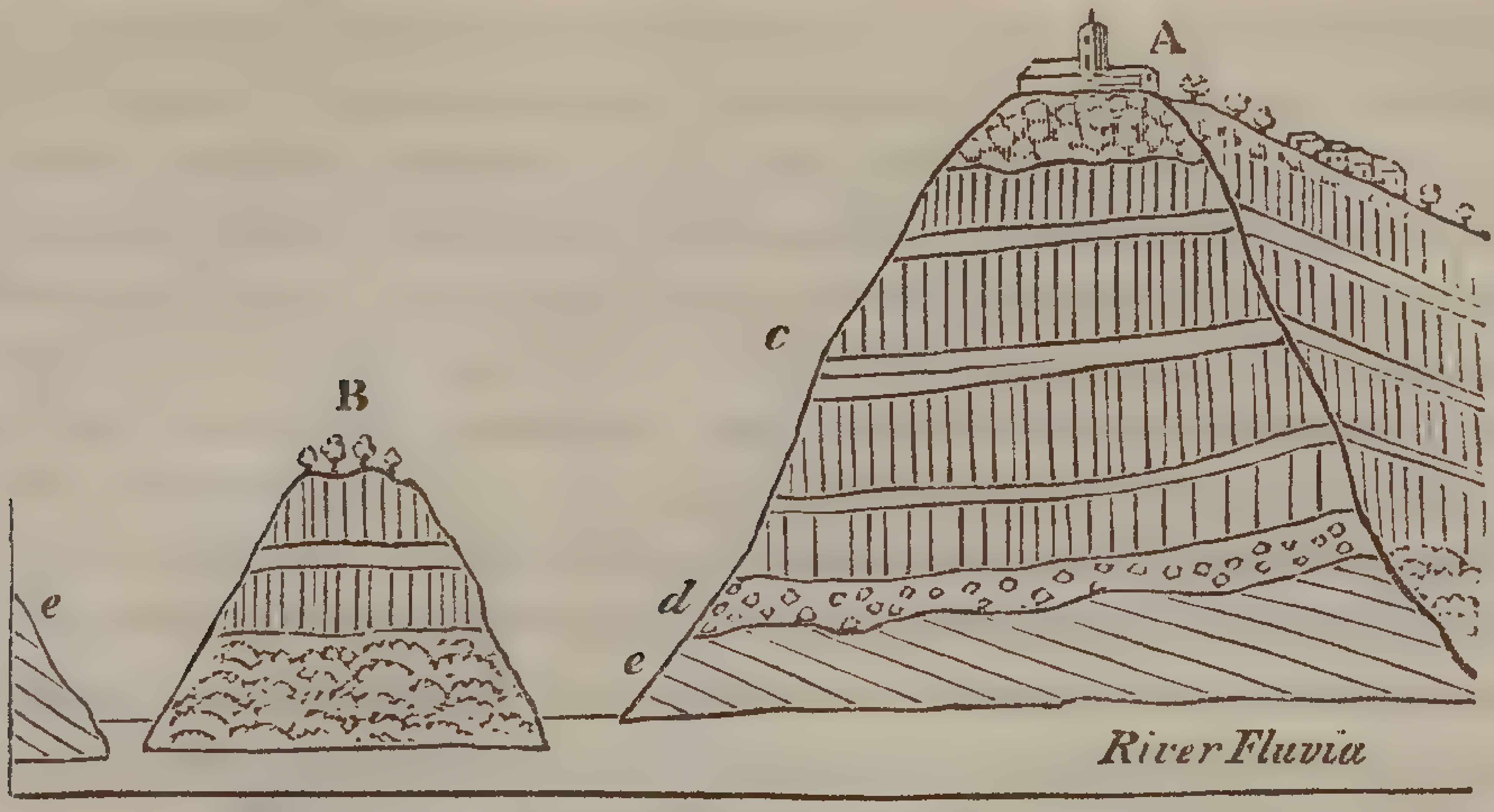
The deepest excavation made by a river through lava, which I observed in this part of Spain, is seen in the bottom of a valley near San Feliu de Palleróls, opposite the Castell de Stolles. The lava there has filled up the bottom of a valley, and a narrow ravine has been cut through it to the depth of 100 feet. In the lower part the lava has a columnar structure. A great number of ages were probably required for the erosion of so deep a ravine; but we have no reason to infer that this current is of higher antiquity than those of the plain near Olot. The fall of the ground, and consequent velocity of the stream, being in this case greater, a more considerable volume of rock may have been removed in the same time.

I shall describe one more section (fig. 670.) to elucidate the phenomena of this district. A lava-stream, flowing from a ridge of hills on the east of Olot, descends a considerable slope, until it reaches the valley of the river Fluvia. Here, for the first time, it comes in contact with running water, which has removed a portion, and laid open its internal structure in a precipice about 130 feet in height, at the edge of which stands the town of Castell Follit.

By the junction of the rivers Fluvia and Teronel, the mass of lava has been cut away on two sides; and the insular rock B (fig. 670.) has been left, which was probably never so high as the cliff A, as it may have constituted the lower part of the sloping side of the original current.

From an examination of the vertical cliffs, it appears that the upper part of the lava on which the town is built is scoriaceous, passing downwards into a spheroidal basalt; some of the huge spheroids being no less than 6 feet in diameter. Below this is a

Fig. 670.



Section at Castell Follit.

A. Church and town of Castell Follit, overlooking precipices of basalt.
B. Small island, on each side of which branches of the river Teronel flow to meet the Fluvia.
c. Precipice of basaltic lava, chiefly columnar, about 130 feet in height.
d. Ancient alluvium, underlying the lava-current.
e. Inclined strata of sandstone.

more compact basalt, with crystals of olivine. There are in all five distinct ranges of basalt, the uppermost spheroidal, and the rest prismatic, separated by thinner beds not columnar, and some of which are schistose. These were probably formed by successive flows of lava, whether during the same eruption or at different periods. The whole mass rests on alluvium, ten or twelve feet in thickness, composed of pebbles of limestone and quartz, but without any intermixture of igneous rocks; in which circumstance alone it appears to differ from the modern gravel of the Fluvia.

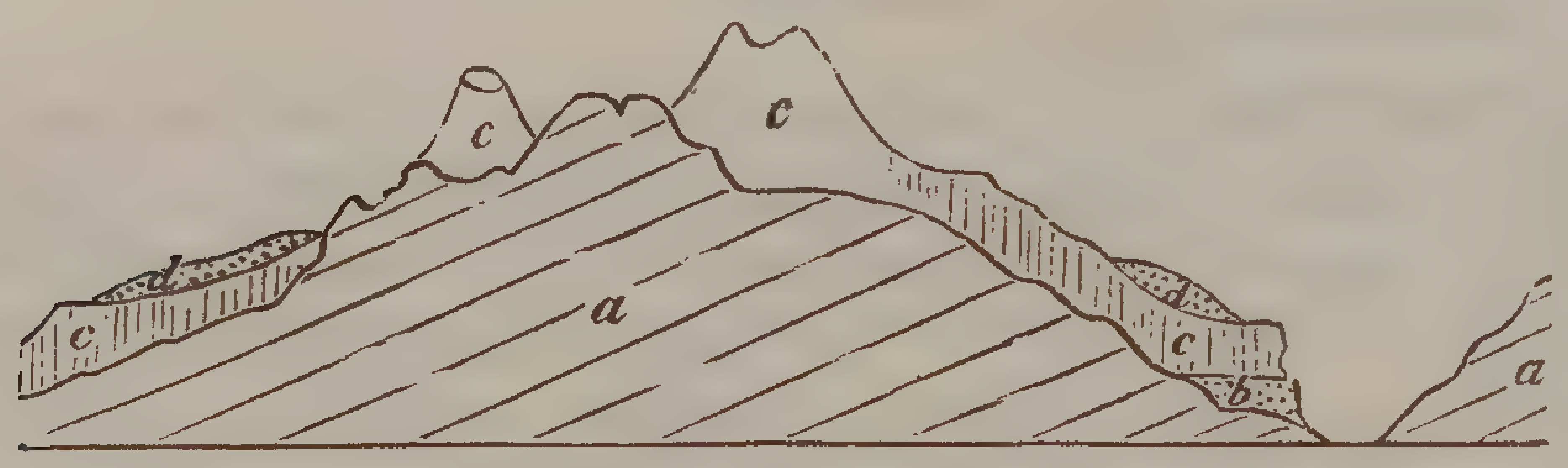
Bufadors. — The volcanic rocks near Olot have often a cavernous structure, like some of the lavas of Etna; and in many parts of the hill of Batet, in the environs of the town, the sound returned by the earth, when struck, is like that of an archway. At the base of the same hill are the mouths of several subterranean caverns, about twelve in number, called in the country "bufadors;" from which a current of cold air issues during summer, but in winter it is said to be scarcely perceptible. I visited one of these bufadors in the beginning of August, 1830, when the heat of the season was unusually intense, and found a cold wind blowing from it, which may easily be explained; for as the external air, when rarefied by heat, ascends, the pressure of the colder and heavier air of the caverns in the interior of the mountain causes it to rush out to supply its place.

In regard to the age of these Spanish volcanos, attempts have been made to prove, that in this country, as well as in Auvergne and the Eifel, the earliest inhabitants were eye-witnesses to the volcanic action. In the year 1421, it is said, when Olot was destroyed by an earthquake, an eruption broke out near Amer, and consumed the town. The researches of Don Francisco Bolos have, I think, shown, in the most satisfactory manner, that there is no good historical foundation for the latter part of this story; and any geologist who has visited Amer must be convinced that there never was any eruption on that spot. It is true that, in the year above mentioned, the whole of Olot, with the exception of a single house, was cast down by an earthquake; one of those shocks which, at distant intervals during the last five centuries, have shaken the Pyrenees, and particularly the country between Perpignan and Olot, where the movements, at the period alluded to, were most violent.

The annihilation of the town may, perhaps, have been due to the cavernous nature of the subjacent rocks; for Catalonia is beyond the line of those European earthquakes which have, within the period of history, destroyed towns throughout extensive areas.

As we have no historical records, then, to guide us in regard to the extinct volcanos, we must appeal to geological monuments. The annexed diagram (fig. 671.) will present to the reader, in a synoptical form, the results obtained from numerous sections.

Fig. 671.



Superposition of rocks in the volcanic district of Catalonia.

a. Sandstone and nummulitic limestone.
b. Older alluvium without volcanic pebbles.
c. Cones of scoriæ and lava. *d.* Newer alluvium.

The more modern alluvium (*d*) is partial, and has been formed by the action of rivers and floods upon the lava; whereas the older gravel (*b*) was strewed over the country before the volcanic eruptions. In neither have any organic remains been discovered; so that we can merely affirm as yet, that the volcanos broke out after the elevation of some of the newest rocks of the mummulitic (Eocene) series of Catalonia, and before the formation of an alluvium (*d*) of unknown date. The integrity of the cones merely shows that the country has not been agitated by violent earthquakes, or subjected to the action of any great flood since their origin.

East of Olot, on the Catalonian coast, marine tertiary strata occur, which, near Barcelona, attain the height of about 500 feet. From the shells which I collected, these strata appear to correspond in age with the Subapennine beds; and it is not improbable that their upheaval from beneath the sea took place during the period of volcanic eruption round Olot. In that case these eruptions may have occurred at the close of the Older Pliocene era, but perhaps subsequently, for their age is at present quite uncertain.

Volcanic rocks of the Eifel. — The chronological relations of the volcanic rocks of the Lower Rhine and the Eifel are also involved in a considerable degree of ambiguity; but we know that some portion of them were coeval with certain tertiary deposits called

"Brown-Coal" by the Germans, which probably belong in part to the Miocene, and in part to the Upper Eocene, epoch.

This Brown-Coal is seen on both sides of the Rhine, in the neighbourhood of Bonn, resting unconformably on highly inclined and vertical strata of Silurian and Devonian rocks. Its geographical position, and the space occupied by the volcanic rocks, both of the Westerwald and Eifel, will be seen by referring to the map (fig. 672.), for which I am indebted to Mr. Horner, whose residence for some years in the country enabled him to verify the maps of MM. Noeggerath and Von Oeynhausen, from which that now given has been principally compiled.*

Fig. 672.

Map of the volcanic region of the Upper and Lower Eifel.

1 2 3 4 5 English Miles.

░ Volcanic District. { A. of the Upper Eifel. B. of the Lower Eifel.

⊕ Points of eruption, with craters and scoriæ.

▨ Trachyte.

● Basalt.

☰ Brown-coal.

N. B. The country in that part of the map which is left blank is composed of inclined Silurian and Devonian rocks.

The Brown-Coal formation of that region consists of beds of loose sand, sandstone, and conglomerate, clay with nodules of clay-ironstone, and occasionally silex. Layers of light brown, and sometimes black lignite are interstratified with the clays and sands, and often

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* Horner, Trans. of Geol. Soc. 2d ser. vol. v.

irregularly diffused through them. They contain numerous impressions of leaves and stems of trees, and are extensively worked for fuel, whence the name of the formation.

In several places, layers of trachytic tuff are interstratified, and in these tuffs are leaves of plants identical with those found in the brown-coal, showing that, during the period of the accumulation of the latter, some volcanic products were ejected.

Mr. Von Decken in his work on the Siebengebirge*, has given a copious list of the animal and vegetable remains of the freshwater strata associated with the brown-coal. Plants of the genera *Flabellaria*, *Ceanothus*, and *Daphnogene*, including *D. cinnamomifolia* (fig. 169. p. 192.) occur in these beds, with nearly 150 other plants, if we include all which have been named from the somewhat uncertain data furnished by leaves. They are referred for the most part to living genera, but to extinct species. Among the animal remains, both vertebrate and invertebrate, many are peculiar, while some few, such as *Littorinella acuta*, Desh., help to approximate these strata with some of the upper freshwater portions of the Mayence basin. The marine base of the Mayence series consists of sandy strata closely allied in geological date, as we have already seen, p. 191., to the Limburg group, called Upper Eocene in this work. But in regard to the Rhenish freshwater deposits near Bonn, so large a proportion of the plants, insects, fish, batrachians, and other fossils are such as have been met with nowhere else, that we cannot as yet assign to them a very definite place in the chronological series. They were undoubtedly formed during that long interval of time which separated the Nummulitic from the Falunian tertiary formations, so that they are newer than the Middle Eocene, and older than the Miocene strata of our Table given at page 105. The classification of the deposits belonging to this interval must still be regarded as debatable ground, very different opinions being entertained on the subject by geologists of high authority. Should a passage be eventually made out from the tertiaries of the north of Germany, on which the labours of M. Beyrich have thrown so much light, to the faluns of the Loire, by the discovery of beds intermediate in age and paleontological characters, the best line of demarcation that we can adopt is that proposed by M. Hébert, according to which all the Limburg beds, the Grès de Fontainebleau, the lower part of the Mayence basin, and the Hempstead beds of the Isle of Wight (see p. 193.) are classed as Lower Miocene, while the Faluns rank as Upper Miocene. Between these formations there is still so vast an hiatus that I have thought it inexpedient, for reasons before explained, to unite them under a common name.†

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* Geognost. Beschreib. des Siebengebirges am Rhein. Bonn, 1852.

† While this sheet was passing through the press, a valuable paper on the Brown-Coal and other deposits of the Mayence Basin, by William J. Hamilton, Esq., P. G. S., has been published (Geol. Quart. Journ. vol. x. p. 254), in which the question of classification above alluded to is discussed. Whatever terminology be adopted, I would strongly urge the necessity of

The fishes of the brown-coal near Bonn are found in a bituminous shale, called paper-coal, from being divisible into extremely thin leaves. The individuals are very numerous; but they appear to belong to a small number of species, some of which were referred by Agassiz to the genera *Leuciscus*, *Aspius*, and *Perca*. The remains of frogs also, of extinct species, have been discovered in the paper-coal; and a complete series may be seen in the museum at Bonn, from the most imperfect state of the tadpole to that of the full-grown animal. With these a salamander, scarcely distinguishable from the recent species, has been found, and the remains of many insects.

A vast deposit of gravel, chiefly composed of pebbles of white quartz, but containing also a few fragments of other rocks, lies over the brown-coal, forming sometimes only a thin covering, at others attaining a thickness of more than 100 feet. This gravel is very distinct in character from that now forming the bed of the Rhine. It is called "Kiesel gerölle" by the Germans, often reaches great elevations, and is covered in several places with volcanic ejections. It is evident that the country has undergone great changes in its physical geography since this gravel was formed; for its position has scarcely any relation to the existing drainage, and the great valley of the Rhine and all the more modern volcanic rocks of the same region are posterior to it in date.

Some of the newest beds of volcanic sand, pumice, and scoriæ are interstratified near Andernach and elsewhere with the loam called loess, which was before described as being full of land and freshwater shells of recent species, and referable to the Post-Pliocene period. I have before hinted (see p. 124.) that this intercalation of volcanic matter between beds of loess may possibly be explained without supposing the last eruptions of the Lower Eifel to have taken place so recently as the era of the deposition of the loess.

The igneous rocks of the Westerwald, and of the mountains called the Siebengebirge, consist partly of basaltic and partly of trachytic lavas, the latter being in general the more ancient of the two. There are many varieties of trachyte, some of which are highly crystalline, resembling a coarse-grained granite, with large separate crystals of felspar. Trachytic tuff is also very abundant. These formations, some of which were certainly contemporaneous with the origin of the brown-coal, were the first of a long series of eruptions, the more recent of which happened when the country had acquired nearly all its present geographical features.

Newer volcanos of the Eifel. — Lake-craters. — As I recognized in the more modern volcanos of the Eifel characters distinct from any previously observed by me in those of France, Italy, or Spain, I shall briefly describe them. The fundamental rocks of the district are grey and red sandstones and shales, with some associated limestones, replete with fossils of the Devonian or Old Red Sandstone

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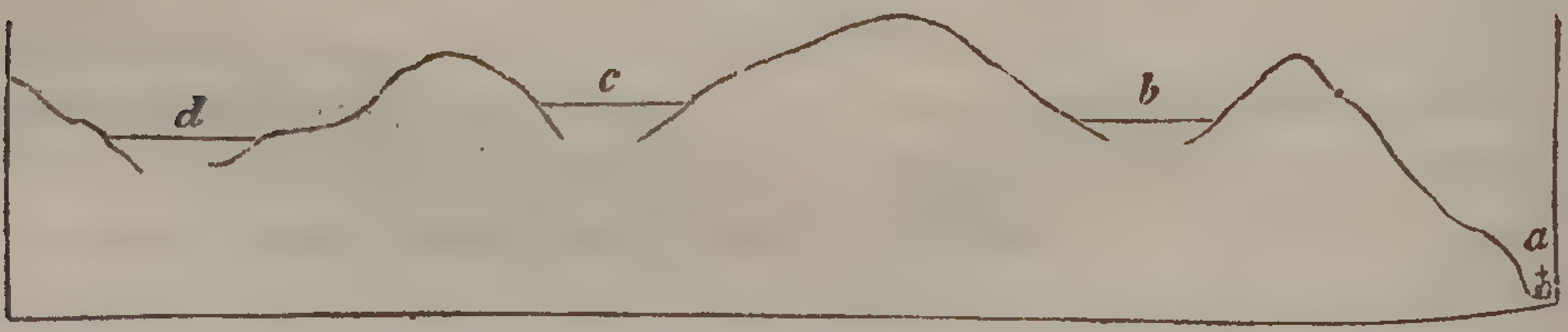
referring the Hempstead beds of the Isle of Wight and the Limburg strata to one and the same period, whether it be named Lower Miocene or Upper Eocene.

group. The volcanos broke out in the midst of these inclined strata, and when the present systems of hills and valleys had already been formed. The eruptions occurred sometimes at the bottom of deep valleys, sometimes on the summit of hills, and frequently on intervening platforms. In travelling through this district we often fall upon them most unexpectedly, and may find ourselves on the very edge of a crater before we had been led to suspect that we were approaching the site of any igneous outburst. Thus, for example, on arriving at the village of Gemund, immediately south of Daun, we leave the stream, which flows at the bottom of a deep valley in which strata of sandstone and shale crop out. We then climb a steep hill, on the surface of which we see the edges of the same strata dipping inwards towards the mountain. When we have ascended to a considerable height, we see fragments of scoriæ sparingly scattered over the surface; until, at length, on reaching the summit, we find ourselves suddenly on the edge of a *tarn*, or deep circular lake-basin (see fig. 673.).

Fig. 673.

The Gemunder Maar.

Fig. 674.



a. Village of Gemund.
b. Gemunder Maar.
c. Weinfelder Maar.
d. Schalkenmehren Maar.

This, which is called the Gemunder Maar, is one of three lakes which are in immediate contact, the same ridge forming the barrier of two neighbouring cavities. On viewing the first of these (fig. 673.), we recognize the ordinary form of a crater, for which we have been prepared by the occurrence of scoriæ scattered over the surface of the soil. But on examining the walls of the crater we find precipices of sandstone and shale which exhibit no signs of the action of heat; and we look in vain for those beds of lava and scoriæ, dipping in opposite directions on every side, which we have been accustomed to consider as characteristic of volcanic vents. As we proceed, however, to the opposite side of the lake, and afterwards visit the craters *c* and *d* (fig. 674.), we find a considerable quantity of scoriæ and some lava, and see the whole surface of the soil sparkling with volcanic sand, and strewed with ejected fragments of half-fused shale, which preserves its laminated texture in the interior, while it has a vitrified or scoriform coating.

A few miles to the south of the lakes above mentioned occurs the Pulvermaar of Gillenfeld, an oval lake of very regular form, and surrounded by an unbroken ridge of fragmentary materials, consisting of ejected shale and sandstone, and preserving a uniform height of about 150 feet above the water. The side slope in the interior is at an angle of about 45 degrees; on the exterior, of 35 degrees. Volcanic substances are intermixed very sparingly with the ejections, which in this place entirely conceal from view the stratified rocks of the country.*

The Meerfelder Maar is a cavity of far greater size and depth, hollowed out of similar strata; the sides presenting some abrupt sections of inclined secondary rocks, which in other places are buried under vast heaps of pulverized shale. I could discover no scoriæ amongst the ejected materials, but balls of olivine and other volcanic substances are mentioned as having been found.† This cavity, which we must suppose to have discharged an immense volume of gas, is nearly a mile in diameter, and is said to be more than one hundred fathoms deep. In the neighbourhood is a mountain called the Mosenberg, which consists of red sandstone and shale in its lower parts, but supports on its summit a triple volcanic cone, while a distinct current of lava is seen descending the flanks of the mountain. The edge of the crater of the largest cone reminded me much of the form and characters of that of Vesuvius; but I was much struck with the precipitous and almost overhanging wall or parapet which the scoriæ presented towards the exterior, as at *a b* (fig. 675.); which I can only explain by supposing that fragments of red-hot lava, as they fell round the vent, were cemented together into one compact mass, in consequence of continuing to be in a half-melted state.

Fig. 675.

Stratified rocks. *v*. Volcanic.

Outline of the Mosenberg, Upper Eifel.

If we pass from the Upper to the Lower Eifel, from A to B (see map, p. 543.), we find the celebrated lake-crater of Laach, which has a greater resemblance than any of those before mentioned to the Lago di Bolsena, and others in Italy, — being surrounded by a ridge

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* Scrope, Edin. Journ. of Science, June, 1826, p. 145.

† Hibbert, Extinct Volcanos of the Rhine, p. 24.

of gently sloping hills, composed of loose tuffs, scoriæ, and blocks of a variety of lavas.

One of the most interesting volcanos on the left bank of the Rhine near Bonn is called the Roderberg. It forms a circular crater nearly a quarter of a mile in diameter, and 100 feet deep, now covered with fields of corn. The highly inclined strata of ancient sandstone and shale rise even to the rim of one side of the crater; but they are overspread by quartzose gravel, and this again is covered by volcanic scoriæ and tufaceous sand. The opposite wall of the crater is composed of cinders and scorified rock, like that at the summit of Vesuvius. It is quite evident that the eruption in this case burst through the sandstone and alluvium which immediately overlies it; and I observed some of the quartz pebbles mixed with scoriæ on the flanks of the mountain, as if they had been cast up into the air, and had fallen again with the volcanic ashes. I have already observed, that a large part of this crater has been filled up with the loess (p. 123.).

The most striking peculiarity of a great many of the craters above described, is the absence of any signs of alteration or torrefaction in their walls, when these are composed of regular strata of ancient sandstone and shale. It is evident that the summits of hills formed of the above-mentioned stratified rocks have, in some cases, been carried away by gaseous explosions, while at the same time no lava, and often a very small quantity only of scoriæ, has escaped from the newly formed cavity. There is, indeed, no feature in the Eifel volcanos more worthy of note, than the proofs they afford of very copious aëriform discharges, unaccompanied by the pouring out of melted matter, except, here and there, in very insignificant volume. I know of no other extinct volcanos where gaseous explosions of such magnitude have been attended by the emission of so small a quantity of lava. Yet I looked in vain in the Eifel for any appearances which could lend support to the hypothesis, that the sudden rushing out of such enormous volumes of gas had ever lifted up the stratified rocks immediately around the vent, so as to form conical masses, having their strata dipping outwards on all sides from a central axis, as is assumed in the theory of elevation craters, alluded to in Chap. XXIX.

Trass. — In the Lower Eifel, eruptions of trachytic lava preceded the emission of currents of basalt, and immense quantities of pumice were thrown out wherever trachyte issued. The tufaceous alluvium called *trass*, which has covered large areas in this region and choked up some valleys now partially re-excavated, is unstratified. Its base consists almost entirely of pumice, in which are included fragments of basalt and other lavas, pieces of burnt shale, slate, and sandstone, and numerous trunks and branches of trees. If this trass was formed during the period of volcanic eruptions, it may perhaps have originated in the manner of the moya of the Andes.

We may easily conceive that a similar mass might now be produced, if a copious evolution of gases should occur in one of the lake basins. The water might remain for weeks in a state of violent ebullition, until it became of the consistency of mud, just as the sea continued to be charged with red mud round Graham's Island, in the Mediterranean, in the year 1831. If a breach should then be made in the side of the cone, the flood would sweep away great heaps of ejected fragments of shale and sandstone, which would be borne down into the adjoining valleys. Forests might be torn up by such a flood, and thus the occurrence of the numerous trunks of trees dispersed irregularly through the trass, can be explained.

Hungary.—M. Beudant, in his elaborate work on Hungary, describes five distinct groups of volcanic rocks, which although nowhere of great extent, form striking features in the physical geography of that country, rising as they do abruptly from extensive plains composed of tertiary strata. They may have constituted islands in the ancient sea, as Santorin and Milo now do in the Grecian Archipelago; and M. Beudant has remarked that the mineral products of the last-mentioned islands resemble remarkably those of the Hungarian extinct volcanos, where many of the same minerals, as opal, calcedony, resinous silex (*silex resinite*), pearlite, obsidian, and pitchstone abound.

The Hungarian lavas are chiefly felspathic, consisting of different varieties of trachyte; many are cellular, and used as millstones; some so porous and even scoriform as to resemble those which have issued in the open air. Pumice occurs in great quantity; and there are conglomerates, or rather breccias, wherein fragments of trachyte are bound together by pumiceous tuff, or sometimes by silex.

It is probable that these rocks were permeated by the waters of hot springs, impregnated, like the Geysers, with silica; or in some instances, perhaps, by aqueous vapours, which, like those of Lancerote, may have precipitated hydrate of silica.

By the influence of such springs or vapours the trunks and branches of trees washed down during floods, and buried in tuffs on the flanks of the mountains, are supposed to have become silicified. It is scarcely possible, says M. Beudant, to dig into any of the pumiceous deposits of these mountains without meeting with opalized wood, and sometimes entire silicified trunks of trees of great size and weight.

It appears from the species of shells collected principally by M. Boué, and examined by M. Deshayes, that the fossil remains imbedded in the volcanic tuffs, and in strata alternating with them in Hungary, are of the Miocene type, and not identical, as was formerly supposed, with the fossils of the Paris basin.

CHAPTER XXXII.

ON THE DIFFERENT AGES OF THE VOLCANIC ROCKS—*continued.*

Volcanic rocks of the Pliocene, Miocene, and Eocene periods continued—Auvergne—Mont Dor—Breccias and alluviums of Mont Perrier, with bones of quadrupeds—River dammed up by lava-current—Range of minor cones from Auvergne to the Vivarais—Monts Dome—Puy de Côme—Puy de Pariou—Cones not denuded by general flood—Velay—Bones of quadrupeds buried in scoriæ—Cantal—Eocene volcanic rocks—Tuffs near Clermont—Hill of Gergovia—Trap of Cretaceous period—Oolitic period—New Red Sandstone period—Carboniferous period—Old Red Sandstone period—"Rock and Spindle" near St. Andrew's—Silurian period—Cambrian volcanic rocks.

Volcanic Rocks of Auvergne.—The extinct volcanos of Auvergne and Cantal in Central France seem to have commenced their eruptions in the Upper Eocene period, but to have been most active during the Miocene and Pliocene eras. I have already alluded to the grand succession of events, of which there is evidence in Auvergne since the last retreat of the sea (see p. 197.).

The earliest monuments of the tertiary period in that region are lacustrine deposits of great thickness (2. fig. 676. p. 552.), in the lowest conglomerates of which are rounded pebbles of quartz, mica-schist, granite, and other non-volcanic rocks, without the slightest intermixture of igneous products. To these conglomerates succeed argillaceous and calcareous marls and limestones (3. fig. 676.), containing Upper Eocene shells and bones of mammalia, the higher beds of which sometimes alternate with volcanic tuff of contemporaneous origin. After the filling up or drainage of the ancient lakes, huge piles of trachytic and basaltic rocks, with volcanic breccias, accumulated to a thickness of several thousand feet, and were superimposed upon granite, or the contiguous lacustrine strata. The greater portion of these igneous rocks appear to have originated during the Miocene and Pliocene periods; and extinct quadrupeds of those eras, belonging to the genera Mastodon, Rhinoceros, and others, were buried in ashes and beds of alluvial sand and gravel, which owe their preservation to overspreading sheets of lava.

In Auvergne the most ancient and conspicuous of the volcanic masses is Mont Dor, which rests immediately on the granitic rocks standing apart from the freshwater strata.* This great mountain rises suddenly to the height of several thousand feet above the surrounding platform, and retains the shape of a flattened and somewhat

* See the Map, p. 196.

irregular cone, all the sides sloping more or less rapidly, until their inclination is gradually lost in the high plain around. This cone is composed of layers of scoriæ, pumice-stones, and their fine detritus, with interposed beds of trachyte and basalt, which descend often in uninterrupted sheets, until they reach and spread themselves round the base of the mountain.* Conglomerates, also, composed of angular and rounded fragments of igneous rocks, are observed to alternate with the above; and the various masses are seen to dip off from the central axis, and to lie parallel to the sloping flanks of the mountain.

The summit of Mont Dor terminates in seven or eight rocky peaks, where no regular crater can now be traced, but where we may easily imagine one to have existed, which may have been shattered by earthquakes, and have suffered degradation by aqueous agents. Originally, perhaps, like the highest crater of Etna, it may have formed an insignificant feature in the great pile, and may frequently have been destroyed and renovated.

According to some geologists, this mountain, as well as Vesuvius, Etna, and all large volcanos, has derived its dome-like form not from the preponderance of eruptions from one or more central points, but from the upheaval of horizontal beds of lava and scoriæ. I have explained my reasons for objecting to this view in Chap. XXIX., when speaking of Palma, and in the Principles of Geology.† The average inclination of the dome-shaped mass of Mont Dor is 8° 6′, whereas in Mounts Loa and Kea, before mentioned, in the Sandwich Islands (see fig. 640. p. 494.), the flanks of which have been raised by recent lavas, we find from Mr. Dana's description that the one has a slope of 6° 30′, the other of 7° 46′. We may, therefore, reasonably question whether there is any absolute necessity for supposing that the basaltic currents of the ancient French volcano were at first more horizontal than they are now. Nevertheless it is highly probable that during the long series of eruptions required to give rise to so vast a pile of volcanic matter, which is thickest at the summit or centre of the dome, some dislocation and upheaval took place; and during the distension of the mass, beds of lava and scoriæ may, in some places, have acquired a greater, in others a less inclination, than that which at first belonged to them.

Respecting the age of the great mass of Mont Dor, we cannot come at present to any positive decision, because no organic remains have yet been found in the tuffs, except impressions of the leaves of trees of species not yet determined. We may certainly conclude, that the earliest eruptions were posterior in origin to those grits and conglomerates of the freshwater formation of the Limagne which contain no pebbles of volcanic rocks; while, on the other hand, some eruptions took place before the great lakes were drained, and others

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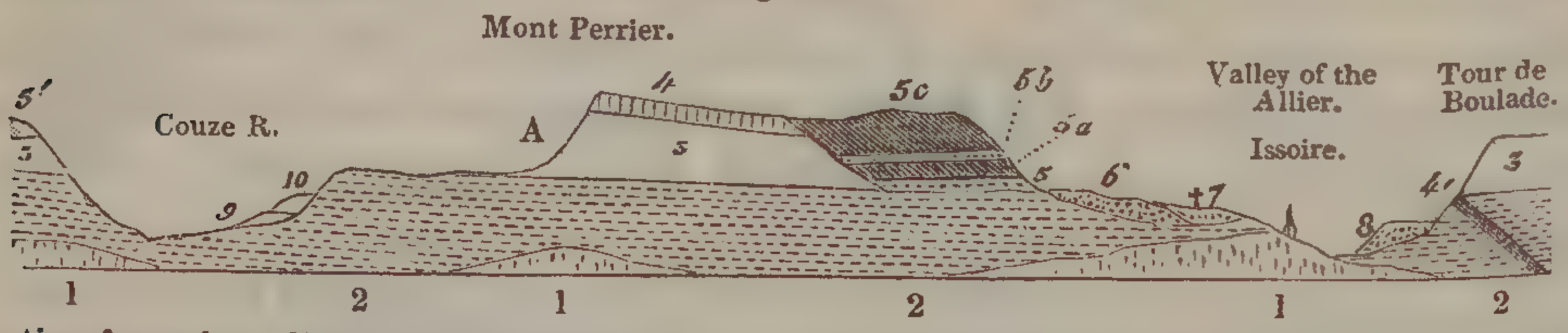
* Scrope's Central France, p. 98.

† See chaps. xxiv., xxv., and xxvi., 7th, 8th, and 9th editions.

occurred after the desiccation of those lakes, and when deep valleys had already been excavated through freshwater strata.

In the annexed section, I have endeavoured to explain the geological structure of a portion of Auvergne, which I re-examined in 1843.*

Fig. 676.



Section from the valley of the Couze at Nechers, through Mont Perrier and Issoire, to the Valley of the Allier and the Tour de Boulade, Auvergne.

10. Lava-current of Tartaret near its termination at Nechers.
9. Bone-bed, red sandy clay under the lava of Tartaret.
8. Bone-bed of the Tour de Boulade.
7. Alluvium newer than No. 6.
6. Alluvium with bones of hippopotamus.
5 *c*. Trachytic breccia resembling 5 *a*.
5 *b*. Upper bone-bed of Perrier, gravel, &c.
5 *a*. Pumiceous breccia and conglomerate, angular masses of trachyte, quartz, pebbles, &c.
5. Lower bone-bed of Perrier, ochreous sand and gravel.
4 *a*. Basaltic dike.
4. Basaltic platform.
3. Upper freshwater beds, limestone, marl, gypsum, &c.
2. Lower freshwater formation, red clay, green sand, &c.
1. Granite.

It may convey some idea to the reader of the long and complicated series of events, which have occurred in that country, since the first lacustrine strata (No. 2.) were deposited on the granite (No. 1.). The changes of which we have evidence are the more striking, because they imply great denudation, without there being any proofs of the intervention of the sea during the whole period. It will be seen that the upper freshwater beds (No. 3.), once formed in a lake, must have suffered great destruction before the excavation of the valleys of the Couze and Allier had begun. In these freshwater beds, Upper Eocene fossils, as described in Chap. XV., have been found. The basaltic dike, 4′, is one of many examples of the intrusion of volcanic matter through the Eocene freshwater beds, and may have been of Upper Eocene or Miocene date, giving rise, when it reached the surface and overflowed, to such platforms of basalt, as often cap the tertiary hills in Auvergne, and one of which (4) is seen on Mont Perrier.

It not unfrequently happens that beds of gravel containing bones of extinct mammalia are detected under these very ancient sheets of basalt, as between No. 4. and the freshwater strata, No. 3., at A, from which it is clear that the surface of No. 3. formed at that period the lowest level at which the waters then draining the country flowed. Next in age to this basaltic platform comes a patch of ochreous sand and gravel (No. 5.), containing many bones of quadrupeds. Upon this rests a pumiceous breccia or conglomerate, with angular masses of trachyte and some quartz pebbles. This deposit is followed by 5 *b* (which is similar to 5) and 5 *c* similar to the trachytic breccia 5 *a*. These two breccias are supposed, from their similarity to others found on Mont Dor, to have descended from the flanks of that mountain

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* See Quarterly Geol. Journ. vol. ii. p. 77.

during eruptions; and the interstratified alluvial deposits contain the remains of mastodon, rhinoceros, tapir, deer, beaver, and quadrupeds of other genera, referable to about forty species, all of which are extinct. I formerly supposed them to belong to the same era as the Miocene faluns of Touraine; but, whether they may not rather be ascribed to the older Pliocene epoch is a question which farther inquiries and comparisons must determine.

Whatever be their date in the tertiary series, they are quadrupeds which inhabited the country when the formations 5 and 5 *c* originated. Probably they were drowned during floods, such as rush down the flanks of volcanos during eruptions, when great bodies of steam are emitted from the crater, or when, as we have seen, both on Etna and in Iceland in modern times, large masses of snow are suddenly melted by lava, causing a deluge of water to bear down fragments of igneous rocks mixed with mud to the valleys and plains below.

It will be seen that the valley of the Issoire, down which these ancient inundations swept, was first excavated at the expense of the formations 2, 3, and 4, and then filled up by the masses 5 and 5 *c*, after which it was re-excavated before the more modern alluviums (Nos. 6. and 7.) were formed. In these again other fossil mammalia 3d
of distinct species have been detected by M. Bravard, the bones of an hippopotamus having been found among the rest.

At length, when the valley of the Allier was eroded at Issoire down to its lowest level, a talus of angular fragments of basalt and freshwater limestone (No. 8.) was formed, called the bone-bed of the Tour de Boulade, from which a great many other mammalia have been 4
collected by MM. Bravard and Pomel. In this assemblage the *Elephas primigenius*, *Rhinoceros tichorinus*, *Deer* (including rein-deer), *Equus*, *Bos*, *Antelope*, *Felis*, and *Canis* were included. Even this deposit seems hardly to be the newest in the neighbourhood, for if we 5
cross from the town of Issoire (see fig. 676.) over Mont Perrier to the adjoining valley of the Couze, we find another bone-bed (No. 9.), overlaid by a current of lava (No. 10.).

The history of this lava-current, which terminates a few hundred yards below the point No. 10., in the suburbs of the village of Nechers, is interesting. It forms a long narrow stripe more than 13 miles in length, at the bottom of the valley of the Couze, which flows out of a lake at the foot of Mont Dor. This lake is caused by a barrier thrown across the ancient channel of the Couze, consisting partly of the volcanic cone called the Puy de Tartaret, formed of loose scoriæ, from the base of which has issued the lava-current before mentioned. The materials of the dam which blocked up the river, and caused the Lac de Chambon, are also, in part, derived from a land-slip which may have happened at the time of the great eruption which formed the cone.

This cone of Tartaret affords an impressive monument of the very different dates at which the igneous eruptions of Auvergne have happened; for it was evidently thrown up at the bottom of the existing valley, which is bounded by lofty precipices composed of sheets of ancient columnar trachyte and basalt, which once flowed at very high levels from Mont Dor.*

When we follow the course of the river Couze, from its source in the lake of Chambon to the termination of the lava-current at Nechers, a distance of thirteen miles, we find that the torrent has in most places cut a deep channel through the lava, the lower portion of which is columnar. In some narrow gorges the water has even had power to remove the entire mass of basaltic rock, though the work of erosion must have been very slow, as the basalt is tough and hard, and one column after another must have been undermined and reduced to pebbles, and then to sand. During the time required for this operation, the perishable cone of Tartaret, composed of sand and ashes, has stood uninjured, proving that no great flood or deluge can have passed over this region in the interval between the eruption of Tartaret and our own times.

If we now return to the section (fig. 676.), I may observe that the lava-current of Tartaret, which has diminished greatly in height and volume near its termination, presents here a steep and perpendicular face 25 feet in height towards the river. Beneath it is the alluvium No. 9., consisting of a red sandy clay, which must have covered the bottom of the valley when the current of melted rock flowed down. The bones found in this alluvium, which I obtained myself, consisted of a species of field-mouse, *Arvicola*, and the molar tooth of an extinct horse, *Equus fossilis*. The other species, obtained from the same bed, are referable to the genera *Sus*, *Bos*, *Cervus*, *Felis*, *Canis*, *Martes*, *Talpa*, *Sorex*, *Lepus*, *Sciurus*, *Mus*, and *Lagomys*, in all no less than forty-three species, all closely allied to recent animals, yet nearly all of them, according to M. Bravard, showing some points of difference, like those which Mr. Owen discovered in the case of the horse above alluded to. The bones, also of a frog, snake, and lizard, and of several birds, were associated with the fossils before enumerated, and several recent land shells, such as *Cyclostoma elegans*, *Helix hortensis*, *H. nemoralis*, *H. lapicida*, and *Clausilia rugosa*. If the animals were drowned by floods, which accompanied the eruptions of the Puy de Tartaret, they would give an exceedingly modern geological date to that event, which must, in that case, have belonged to the Newer-Pliocene, or, perhaps, the Post-Pliocene period. That the current which has issued from the Puy de Tartaret, may nevertheless be very ancient in reference to the events of human history, we may conclude, not only from the divergence of the mammiferous fauna from that of our day, but from the fact that a Roman bridge of such form and construction as continued in use down to the fifth century, but which may be older, is now seen at a place about a mile and a half from St. Nectaire. This ancient bridge spans the river Couze with two arches, each about 14 feet wide. These arches spring from the lava of Tartaret, on both banks, showing that a ravine precisely

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* For a view of Puy de Tartaret and Mont Dor, see Scrope's Volcanos of Central France.

like that now existing, had already been excavated by the river through that lava thirteen or fourteen centuries ago.

In Central France there are several hundred minor cones, like that of Tartaret, a great number of which, like Monte Nuovo, near Naples, may have been principally due to a single eruption. Most of these cones range in a linear direction from Auvergne to the Vivarais, and they were faithfully described so early as the year 1802, by M. de Montlosier. They have given rise chiefly to currents of basaltic lava. Those of Auvergne called the Monts Dome, placed on a granitic platform, form an irregular ridge (see fig. 621. p. 466.), about 18 miles in length and 2 in breadth. They are usually truncated at the summit, where the crater is often preserved entire, the lava having issued from the base of the hill. But frequently the crater is broken down on one side, where the lava has flowed out. The hills are composed of loose scoriæ, blocks of lava, lapilli, and pozzuolana, with fragments of trachyte and granite.

Puy de Côme.—The Puy de Côme and its lava-current, near Clermont, may be mentioned as one of these minor volcanos. This conical hill rises from the granitic platform, at an angle of between 30° and 40°, to the height of more than 900 feet. Its summit presents two distinct craters, one of them with a vertical depth of 250 feet. A stream of lava takes its rise at the western base of the hill, instead of issuing from either crater, and descends the granitic slope towards the present site of the town of Pont Gibaud. Thence it pours in a broad sheet down a steep declivity into the valley of the Sioule, filling the ancient river-channel for the distance of more than a mile. The Sioule, thus dispossessed of its bed, has worked out a fresh one between the lava and the granite of its western bank ; and the excavation has disclosed, in one spot, a wall of columnar basalt about 50 feet high.*

The excavation of the ravine is still in progress, every winter some columns of basalt being undermined and carried down the channel of the river, and in the course of a few miles rolled to sand and pebbles. Meanwhile the cone of Côme remains unimpaired, its loose materials being protected by a dense vegetation, and the hill standing on a ridge not commanded by any higher ground, so that no floods of rain-water can descend upon it. There is no end to the waste which the hard basalt may undergo in future, if the physical geography of the country continue unchanged, no limit to the number of years during which the heap of incoherent and transportable materials called the Puy de Côme may remain in a stationary condition. In this place, therefore, we behold in the results of aqueous and atmospheric agency in past times, a counterpart of what we must expect to recur in future ages.

Lava of Chaluzet.—At another point, farther down the course of the Sioule, we find a second illustration of the same phenomenon in the Puy Rouge, a conical hill to the north of the village of Pranal.

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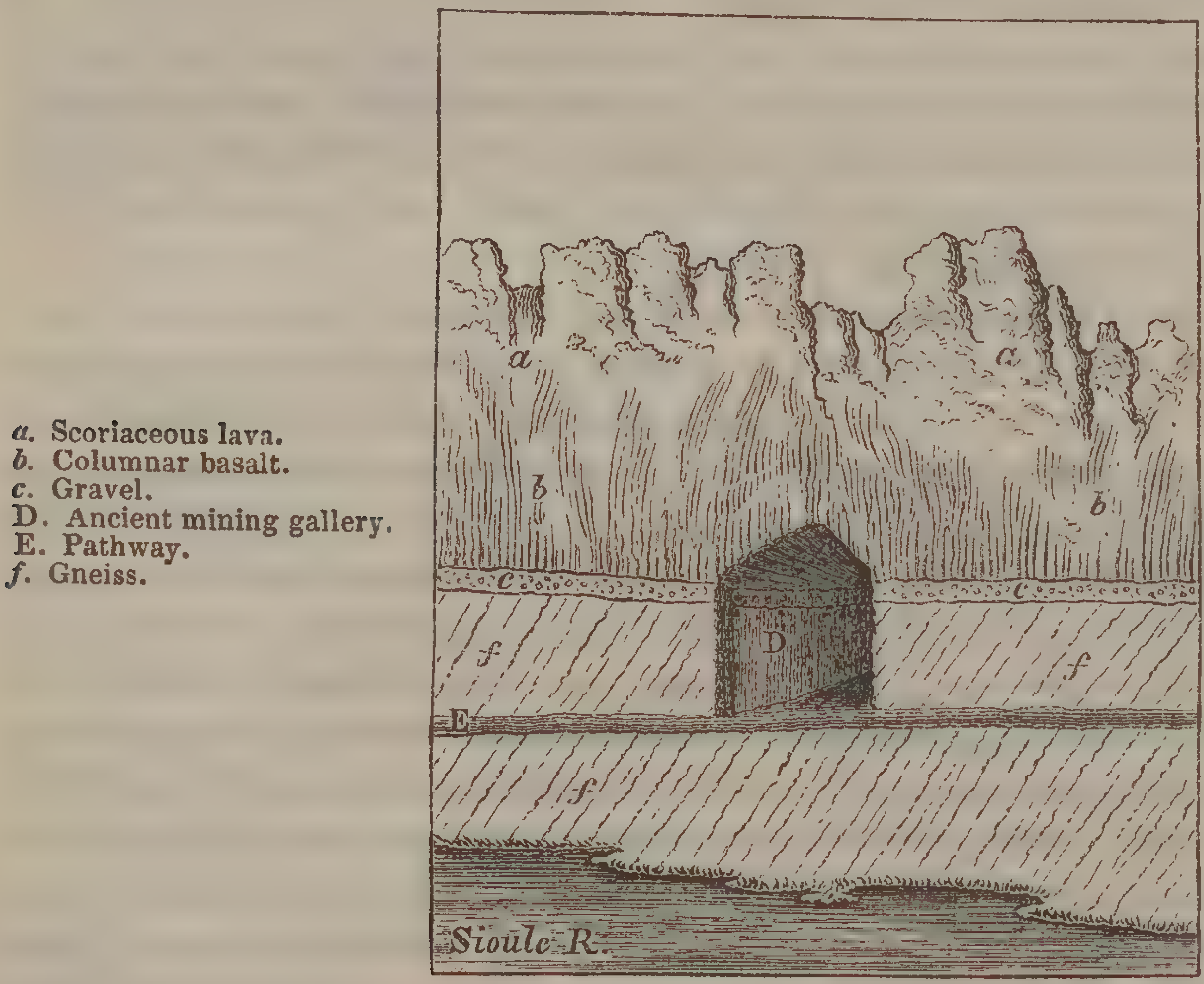
* Scrope's Central France, p. 60., and plate.

The cone is composed entirely of red and black scoriæ, tuff, and volcanic bombs. On its western side, towards the village of Chaluzet, there is a worn-down crater, whence a powerful stream of lava has issued, and flowed into the valley of the Sioule. The river has since excavated a ravine through the lava and subjacent gneiss, to the depth in some places of 400 feet.

On the upper part of the precipice forming the left side of this ravine, we see a great mass of black and red scoriaceous lava becoming more and more columnar towards its base. (See fig. 677.).

Fig. 677.



Lava-current of Chaluzet, Auvergne, near its termination.[*]

Below this is a bed of sand and gravel 3 feet thick, evidently an ancient river-bed, now at an elevation of 25 feet above the channel of the Sioule. This gravel, from which water gushes out, rests upon gneiss, *f*, which has been eroded to the depth of 25 feet at the point where the annexed view is taken. At D, close to the village of Les Combres, the entrance of a gallery is seen, in which lead has been worked in the gneiss. This mine shows that the pebble-bed is continuous, in a horizontal direction, between the gneiss and the volcanic mass. Here again it is quite evident, that, while the basalt was gradually undermined and carried away by the force of running water, the cone whence the lava issued escaped destruction, because it stood upon a platform of gneiss several hundred feet above the level of the valley in which the force of running water was exerted.

Puy de Pariou.—The brim of the crater of the Puy de Pariou, near Clermont, is so sharp, and has been so little blunted by time, that it scarcely affords room to stand upon. This and other cones

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[*] Lyell and Murchison, Ed. New Phil. Journ. 1829.

in an equally remarkable state of integrity have stood, I conceive, uninjured, not *in spite* of their loose porous nature, as might at first be naturally supposed, but in consequence of it. No rills can collect where all the rain is instantly absorbed by the sand and scoriæ, as is remarkably the case on Etna; and nothing but a waterspout breaking directly upon the Puy de Pariou could carry away a portion of the hill, so long as it is not rent or engulphed by earthquakes.

Hence it is conceivable that even those cones which have the freshest aspect and most perfect shape may lay claim to very high antiquity. Dr. Daubeny has justly observed, that had any of these volcanos been in a state of activity in the age of Julius Cæsar, that general, who encamped upon the plains of Auvergne, and laid siege to its principal city (Gergovia, near Clermont), could hardly have failed to notice them. Had there been any record of their eruptions in the time of Pliny or Sidonius Apollinaris, the one would scarcely have omitted to make mention of it in his Natural History, nor the other to introduce some allusion to it among the descriptions of this his native province. This poet's residence was on the borders of the Lake Aidat, which owed its very existence to the damming up of a river by one of the most modern lava-currents.*

Velay.—The observations of M. Bertrand de Doue have not yet established that any of the most ancient volcanos of Velay were in action during the Eocene period. There are beds of gravel in Velay, as in Auvergne, covered by lava at different heights above the channel of the existing rivers. In the highest and most ancient of these alluviums the pebbles are exclusively of granitic rocks; but in the newer, which are found at lower levels, and which originated when the valleys had been cut to a greater depth, an intermixture of volcanic rocks has been observed.

At St. Privat d'Allier a bed of volcanic scoriæ and tuff was discovered by Dr. Hibbert, inclosed between two sheets of basaltic lava; and in this tuff were found the bones of several quadrupeds, some of them adhering to masses of slaggy lava. Among other animals were *Rhinoceros leptorhinus*, *Hyæna spelæa*, and a species allied to the spotted hyæna of the Cape, together with four undetermined species of deer. The manner of the occurrence of these bones reminds us of the published accounts of an eruption of Coseguina, 1835, in Central America (see p. 525.), during which hot cinders and scoriæ fell and scorched to death great numbers of wild and domestic animals and birds.

Plomb du Cantal.—In regard to the age of the igneous rocks of the Cantal, we can at present merely affirm, that they overlie the (Upper?) Eocene lacustrine strata of that country (see Map, p. 196.). They form a great dome-shaped mass, having an average slope of only 4°, which has evidently been accumulated, like the cone of Etna, during a long series of eruptions. It is composed of trachytic, phonolitic, and basaltic lavas, tuffs, and conglomerates, or breccias,

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* Daubeny on Volcanos, p. 14.

forming a mountain several thousand feet in height. Dikes also of phonolite, trachyte, and basalt are numerous, especially in the neighbourhood of the large cavity, probably once a crater, around which the loftiest summits of the Cantal are ranged circularly, few of them, except the Plomb du Cantal, rising far above the border or ridge of this supposed crater. A pyramidal hill, called the Puy Griou, occupies the middle of the cavity.* It is clear that the volcano of the Cantal broke out precisely on the site of the lacustrine deposit before described (p. 205.), which had accumulated in a depression of a tract composed of micaceous schist. In the breccias, even to the very summit of the mountain, we find ejected masses of the freshwater beds, and sometimes fragments of flint, containing Eocene shells. Valleys radiate in all directions from the central heights of the mountain, increasing in size as they recede from those heights. Those of the Cer and Jourdanne, which are more than 20 miles in length, are of great depth, and lay open the geological structure of the mountain. No alternation of lavas with undisturbed Eocene strata has been observed, nor any tuffs containing freshwater shells, although some of these tuffs include fossil remains of terrestrial plants, said to imply several distinct restorations of the vegetation of the mountain in the intervals between great eruptions. On the northern side of the Plomb du Cantal, at La Vissiere, near Murat, is a spot, pointed out on the Map (p. 196.), where freshwater limestone and marl are seen covered by a thickness of about 800 feet of volcanic rock. Shifts are here seen in the strata of limestone and marl.†

In treating of the lacustrine deposits of Central France, in the fifteenth chapter, it was stated that, in the arenaceous and pebbly group of the lacustrine basins of Auvergne, Cantal, and Velay, no volcanic pebbles had ever been detected, although massive piles of igneous rocks are now found in the immediate vicinity. As this observation has been confirmed by minute research, we are warranted in inferring that the volcanic eruptions had not commenced when the older subdivisions of the freshwater groups originated.

In Cantal and Velay no decisive proofs have yet been brought to light that any of the igneous outbursts happened during the deposition of the freshwater strata; but there can be no doubt that in Auvergne some volcanic explosions took place before the drainage of the lakes, and at a time when the Upper Eocene species of animals and plants still flourished. Thus, for example, at Pont du Chateau, near Clermont, a section is seen in a precipice on the right bank of the river Allier, in which beds of volcanic tuff alternate with a freshwater limestone, which is in some places pure, but in others spotted with fragments of volcanic matter, as if it were deposited while showers of sand and scoriæ were projected from a neighbouring vent.‡

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* Mém. de la Soc. Géol. de France, tom. i. p. 175.

† See Lyell and Murchison, Ann. de Sci. Nat., Oct. 1829.

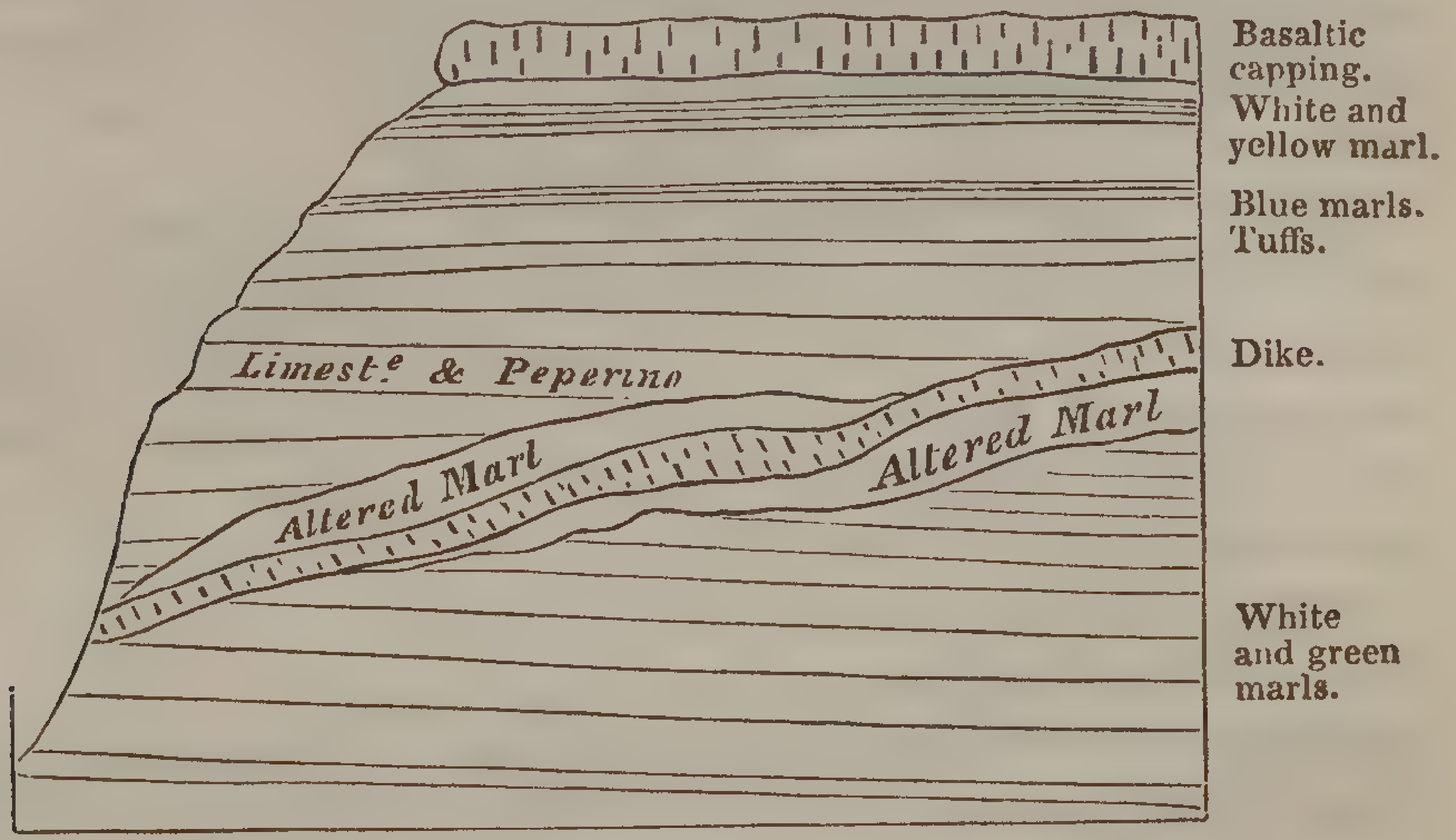
‡ See Scrope's Central France, p. 21.

Another example occurs in the Puy de Marmont, near Veyres, where a freshwater marl alternates with volcanic tuff containing Eocene shells. The tuff or breccia in this locality is precisely such as is known to result from volcanic ashes falling into water, and subsiding together with ejected fragments of marl and other stratified rocks. These tuffs and marls are highly inclined, and traversed by a thick vein of basalt, which, as it rises in the hill, divides into two branches.

Gergovia. — The hill of Gergovia, near Clermont, affords a third example. I agree with MM. Dufrénoy and Jobert that there is no alternation here of a contemporaneous sheet of lava with freshwater strata, in the manner supposed by some other observers*; but the position and contents of some of the associated tuffs, prove them to have been derived from volcanic eruptions which occurred during the deposition of the lacustrine strata.

The bottom of the hill consists of slightly inclined beds of white and greenish marls, more than 300 feet in thickness, intersected by a dike of basalt, which may be studied in the ravine above the village of Merdogne. The dike here cuts through the marly strata at a considerable angle, producing, in general, great alteration and confusion in them for some distance from the point of contact. Above the white and green marls, a series of beds of limestone and marl, containing freshwater shells, are seen to alternate with volcanic tuff. In the lowest part of this division, beds of pure marl alternate with compact fissile tuff, resembling some of the subaqueous tuffs of Italy and Sicily called *peperinos.* Occasionally fragments of scoriæ are visible in this rock. Still higher is seen another group of some thickness, consisting exclusively of tuff, upon which lie other marly strata intermixed with volcanic matter. Among the species of fossil shells which I found in these strata were *Melania inquinata*, a *Unio*,

Fig. 678.



Hill of Gergovia.

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* See Scrope's Central France, p. 7.

and a *Melanopsis*, but they were not sufficient to enable me to determine with precision the age of the formation.

There are many points in Auvergne where igneous rocks have been forced by subsequent injection through clays and marly limestones, in such a manner that the whole has become blended in one confused and brecciated mass, between which and the basalt there is sometimes no very distinct line of demarcation. In the cavities of such mixed rocks we often find calcedony, and crystals of mesotype, stilbite, and arragonite. To formations of this class may belong some of the breccias immediately adjoining the dike in the hill of Gergovia; but it cannot be contended that the volcanic sand and scoriæ interstratified with the marls and limestones in the upper part of that hill were introduced, like the dike, subsequently, by intrusion from below. They must have been thrown down like sediment from water, and can only have resulted from igneous action, which was going on contemporaneously with the deposition of the lacustrine strata.

The reader will bear in mind that this conclusion agrees well with the proofs, adverted to in the fifteenth chapter, of the abundance of silex, travertin, and gypsum precipitated when the upper lacustrine strata were formed; for these rocks are such as the waters of mineral and thermal springs might generate.

Cretaceous period. — Although we have no proof of volcanic rocks erupted in England during the deposition of the chalk and greensand, it would be an error to suppose that no theatres of igneous action existed in the cretaceous period. M. Virlet, in his account of the geology of the Morea, p. 205., has clearly shown that certain traps in Greece, called by him ophiolites, are of this date; as those, for example, which alternate conformably with cretaceous limestone and greensand between Kastri and Damala in the Morea. They consist in great part of diallage rocks and serpentine, and of an amygdaloid with calcareous kernels, and a base of serpentine.

In certain parts of the Morea, the age of these volcanic rocks is established by the following proofs: first, the lithographic limestones of the Cretaceous era are cut through by trap, and then a conglomerate occurs, at Nauplia and other places, containing in its calcareous cement many well-known fossils of the chalk and greensand, together with pebbles formed of rolled pieces of the same ophiolite, which appear in the dikes above alluded to.

Period of Oolite and Lias. — Although the green and serpentinous trap rocks of the Morea belong chiefly to the Cretaceous era, as before mentioned, yet it seems that some eruptions of similar rocks began during the Oolitic period *; and it is probable, that a large part of the trappean masses, called ophiolites in the Apennines, and associated with the limestone of that chain, are of corresponding age.

That some part of the volcanic rocks of the Hebrides, in our own country, originated contemporaneously with the Oolite which they traverse and overlie, has been ascertained by Prof. E. Forbes, in

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* Boblaye and Virlet, Morea, p. 23.

1850. Some of the eruptions in Skye, for example, occurred at the close of the Middle and before the commencement of the Upper Oolitic Period.*

Trap of the New Red Sandstone period.—In the southern part of Devonshire, trappean rocks are associated with New Red Sandstone, and, according to Sir H. de la Beche, have not been intruded subsequently into the sandstone, but were produced by contemporaneous volcanic action. Some beds of grit, mingled with ordinary red marl, resemble sands ejected from a crater; and in the stratified conglomerates occurring near Tiverton are many angular fragments of trap porphyry, some of them one or two tons in weight, intermingled with pebbles of other rocks. These angular fragments were probably thrown out from volcanic vents, and fell upon sedimentary matter then in the course of deposition.†

Carboniferous period. — Two classes of contemporaneous trap rocks have been ascertained by Dr. Fleming to occur in the coal-field of the Forth in Scotland. The newest of these, connected with the higher series of coal-measures, is well exhibited along the shores of the Forth, in Fifeshire, where they consist of basalt with olivine, amygdaloid, greenstone, wacké, and tuff. They appear to have been erupted while the sedimentary strata were in a horizontal position, and to have suffered the same dislocations which those strata have subsequently undergone. In the volcanic tuffs of this age are found not only fragments of limestone, shale, flinty slate, and sandstone, but also pieces of coal.

The other or older class of carboniferous traps are traced along the south margin of Stratheden, and constitute a ridge parallel with the Ochils, and extending from Stirling to near St. Andrews. They consist almost exclusively of greenstone, becoming, in a few instances, earthy and amygdaloidal. They are regularly interstratified with the sandstone, shale, and ironstone of the lower Coal-measures, and, on the East Lomond, with Mountain Limestone.

I examined these trap rocks in 1838, in the cliffs south of St. Andrews, where they consist in great part of stratified tuffs, which are curved, vertical, and contorted, like the associated coal-measures. In the tuff I found fragments of carboniferous shale and limestone, and intersecting veins of greenstone. At one spot, about two miles from St. Andrews, the encroachment of the sea on the cliffs has isolated several masses of trap, one of which (fig. 679.) is aptly called the "rock and spindle," ‡ for it consists of a pinnacle of tuff, which may be compared to a distaff, and near the base is a mass of columnar greenstone, in which the pillars radiate from a centre, and appear at a distance like the spokes of a wheel. The largest diameter of this wheel is about twelve feet, and the polygonal terminations of the

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* Geol. Quart. Journ. 1851, vol. vii. p. 108.

† De la Beche, Geol. Proceedings, vol. ii. p. 198.

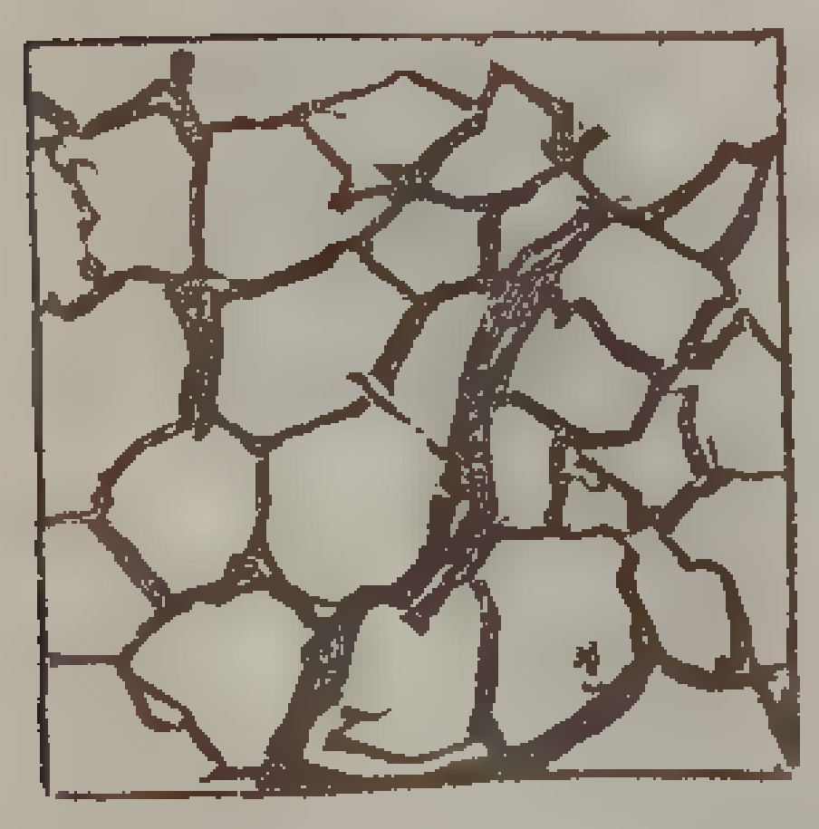
‡ "The rock," as English readers of Burns's poems may remember, is a Scotch term for a distaff.

Fig. 679.

Rock and Spindle, St. Andrews, as seen in 1838.

a. Unstratified tuff. *b.* Columnar greenstone. *c.* Stratified tuff.

Fig. 680.



Columns of Greenstone, seen endwise at *b*, fig. 679.

columns are seen round the circumference (or tire, as it were, of the wheel), as in the accompanying figure. I conceive this mass to be the extremity of a string or vein of greenstone, which penetrated the tuff. The prisms point in every direction, because they were surrounded on all sides by cooling surfaces, to which they always arrange themselves at right angles, as before explained (p. 488.).

A trap dike was pointed out to me by Dr. Fleming, in the parish of Flisk, in the northern part of Fifeshire, which cuts through the grey sandstone and shale forming the lowest part of the Old Red Sandstone. It may be traced for many miles, passing through the amygdaloidal and other traps of the hill called Norman's Law. In its course it affords a good exemplification of the passage from the trappean into the plutonic, or highly crystalline texture. Professor Gustavus Rose, to whom I submitted specimens of this dike, finds the rock, which he calls dolerite, to consist of greenish black augite and Labrador felspar, the latter being the most abundant ingredient. A small quantity of magnetic iron, perhaps titaniferous, is also present. The result of this analysis is interesting, because both the ancient and modern lavas of Etna consist in like manner of augite, Labradorite, and titaniferous iron.

Trap of the Old Red sandstone period.—By referring to the section explanatory of the structure of Forfarshire, already given (p. 48.), the reader will perceive that beds of conglomerate, No. 3., occur in the middle of the Old Red sandstone system, 1, 2, 3, 4. The pebbles in these conglomerates are sometimes composed of granitic and quartzose rocks, sometimes exclusively of different varieties of trap, which, although purposely omitted in the section referred to, are often found either intruding themselves in amorphous masses and dikes into the old fossiliferous tilestones, No. 4., or alternating with them in conformable beds. All the different divisions of the red sandstone, 1, 2, 3, 4, are occasionally intersected by dikes, but they are very rare in Nos. 1. and 2., the upper members of the group consisting of red shale and red sandstone. These phenomena, which occur at the foot of the Grampians, are repeated in the Sidlaw Hills; and it appears that in this part of Scotland volcanic eruptions were most frequent in the earlier part of the Old Red Sandstone period.

The trap rocks alluded to consist chiefly of felspathic porphyry and amygdaloid, the kernels of the latter being sometimes calcareous, often calcedonic, and forming beautiful agates. We meet also with claystone, clinkstone, greenstone, compact felspar, and tuff. Some of these rocks flowed as lavas over the bottom of the sea, and enveloped quartz pebbles which were lying there, so as to form conglomerates with a base of greenstone, as is seen in Lumley Den, in the Sidlaw Hills. On either side of the axis of this chain of hills (see section, p. 48.), the beds of massive trap, and the tuffs composed of volcanic sand and ashes, dip regularly to the south-east or north-west, conformably with the shales and sandstones.

Silurian period.—It appears from the investigations of Sir R. Murchison in Shropshire, that when the lower Silurian strata of that country were accumulating, there were frequent volcanic eruptions beneath the sea; and the ashes and scoriæ then ejected gave rise to a peculiar kind of tufaceous sandstone or grit, dissimilar to the other rocks of the Silurian series, and only observable in places where syenitic and other trap rocks protrude. These tuffs occur on the flanks of the Wrekin and Caer Caradoc, and contain

Silurian fossils, such as casts of encrinites, trilobites, and mollusca. Although fossiliferous, the stone resembles a sandy claystone of the trap family.*

Thin layers of trap, only a few inches thick, alternate, in some parts of Shropshire and Montgomeryshire, with a sedimentary strata of the lower Silurian system. This trap consists of slaty porphyry and granular felspar rock, the beds being traversed by joints like those in the associated sandstone, limestone, and shale, and having the same strike and dip.†

In Radnorshire there is an example of twelve bands of stratified trap, alternating with Silurian schists and flagstones, in a thickness of 350 feet. The bedded traps consist of felspar-porphyry, clinkstone, and other varieties; and the interposed Llandeilo flags are of sandstone and shale, with trilobites and graptolites.‡

Cambrian Volcanic Rocks.—In a former chapter (Ch. XXVII. p. 451.), we have seen that below the Llandeilo and Bala beds of Lower Silurian date there occur, in North Wales, a series of rocks of vast thickness, which may be called Cambrian. The upper subdivision, named by Professor Sedgwick the "Festiniog group," comprises, first, the Arenig Slates, 7000 feet thick in North Wales, in the midst of which dense masses of porphyry, trap-conglomerate, and other igneous rocks, which are supposed by Professor Sedgwick to be of contemporaneous origin, are intercalated; secondly, the Lingula flags underlying the former, and of which the fossils were treated of at p. 452.; thirdly, still lower, the Bangor group or Lower Cambrian, in which bands of felspathic porphyry occur. These last are, in the opinion of Professor Ramsay, intrusive and not of the same date as the associated sedimentary deposits.

Professor Sedgwick has also described, in his account of the geology of Cumberland, various trap rocks which accompany green slates, agreeing in mineral character and aspect with the Arenig Slates, which underlie all the fossiliferous strata of Cumberland, and consist of felspathic and porphyritic rocks and greenstones, occurring not only in dikes, but in conformable beds. Occasionally there is a passage from these igneous rocks to some of the green quartzose slates. These porphyries are supposed to have been produced contemporaneously with the stratified chloritic slates by submarine eruptions oftentimes repeated, the materials of the slates having been supplied, in part at least, from the same source. §

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* Murchison, Silurian System, &c. p. 230.

† Ibid., p. 272.

‡ Ibid., p. 325.

§ Geol. Trans., 2d series, vol. iv. p. 55.

CHAPTER XXXIII.

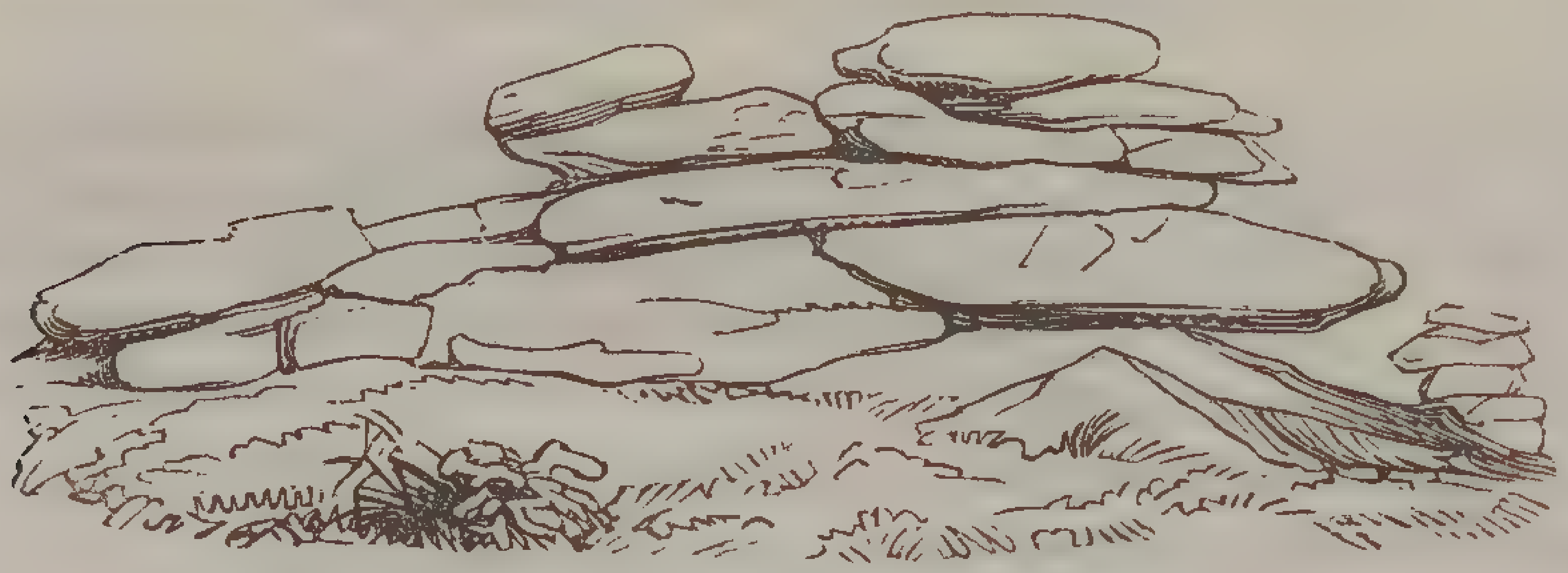
PLUTONIC ROCKS — GRANITE.

General aspect of granite — Decomposing into spherical masses — Rude columnar structure — Analogy and difference of volcanic and plutonic formations — Minerals in granite, and their arrangement — Graphic and porphyritic granite — Mutual penetration of crystals of quartz and felspar — Occasional minerals — Syenite — Syenitic, talcose, and schorly granites — Eurite — Passage of granite into trap — Examples near Christiania and in Aberdeenshire — Analogy in composition of trachyte and granite — Granite veins in Glen Tilt, Cornwall, the Valorsine, and other countries — Different composition of veins from main body of granite — Metalliferous veins in strata near their junction with granite — Apparent isolation of nodules of granite — Quartz veins — Whether plutonic rocks are ever overlying — Their exposure at the surface due to denudation.

THE plutonic rocks may be treated of next in order, as they are most nearly allied to the volcanic class already considered. I have described, in the first chapter, these plutonic rocks as the unstratified division of the crystalline or hypogene formations, and have stated that they differ from the volcanic rocks, not only by their more crystalline texture, but also by the absence of tuffs and breccias, which are the products of eruptions at the earth's surface, or beneath seas of inconsiderable depth. They differ also by the absence of pores or cellular cavities, to which the expansion of the entangled gases gives rise in ordinary lava. From these and other peculiarities it has been inferred, that the granites have been formed at considerable depths in the earth, and have cooled and crystallized slowly under great pressure, where the contained gases could not expand. The volcanic rocks, on the contrary, although they also have risen up from below, have cooled from a melted state more rapidly upon or near the surface. From this hypothesis of the great depth at which the granites originated, has been derived the name of "Plutonic rocks." The beginner will easily conceive that the influence of subterranean heat may extend downwards from the crater of every active volcano to a great depth below, perhaps several miles or leagues, and the effects which are produced deep in the bowels of the earth may, or rather must, be distinct; so that volcanic and plutonic rocks, each different in texture, and sometimes even in composition, may originate simultaneously, the one at the surface, the other far beneath it.

By some writers, all the rocks now under consideration have been comprehended under the name of granite, which is, then, understood to embrace a large family of crystalline and compound rocks, usually found underlying all other formations; whereas we have seen that trap very commonly overlies strata of different ages. Granite often preserves a very uniform character throughout a wide range of territory, forming hills of a peculiar rounded form, usually clad with a scanty vegetation. The surface of the rock is for the most part in a crumbling state, and the hills are often surmounted by piles of stones like the remains of a stratified mass, as in the annexed figure, and sometimes like heaps of boulders, for which they have been mistaken. The exterior of these stones, originally quadrangular, acquires a rounded form by the action of air and water, for the edges and angles waste away more rapidly than the sides. A similar spherical structure has already been described as characteristic of basalt and other volcanic formations, and it must be referred to analogous causes, as yet but imperfectly understood.

Fig. 681.



Mass of granite near the Sharp Tor, Cornwall.

Although it is the general peculiarity of granite to assume no definite shapes, it is nevertheless occasionally subdivided by fissures, so as to assume a cuboidal, and even a columnar, structure. Examples of these appearances may be seen near the Land's End, in Cornwall. (See fig. 682.)

The plutonic formations also agree with the volcanic in having veins or ramifications proceeding from central masses into the adjoining rocks, and causing alterations in these last, which will be presently described. They also resemble trap in containing no organic remains; but they differ in being more uniform in texture, whole mountain masses of indefinite extent appearing to have originated under conditions precisely similar. They also differ in never being scoriaceous or amygdaloidal, and never forming a porphyry with an uncrystalline base, or alternating with tuffs. Nor do they form conglomerates, although there is sometimes an insensible passage from a fine to a coarse-grained granite, and occasionally patches of a fine texture are imbedded in a coarser variety.

Felspar, quartz, and mica are usually considered as the minerals essential to granite, the felspar being most abundant in quantity, and the proportion of quartz exceeding that of mica. These minerals are united in what is termed a confused crystallization; that is to say, there is no regular arrangement of the crystals in granite, as in gneiss (see fig. 704. p. 595.), except in the variety termed graphic granite, which occurs mostly in granitic veins. This variety is a

Fig. 682.

Granite having a cuboidal and rude columnar structure, Land's End, Cornwall.

compound of felspar and quartz, so arranged as to produce an imperfect laminar structure. The crystals of felspar appear to have been first formed, leaving between them the space now occupied by the darker-coloured quartz. This mineral, when a section is made at right angles to the alternate plates of felspar and quartz, presents broken lines, which have been compared to Hebrew characters. The variety of granite called by the French *Pegmatite*, which is a mixture of quartz and common felspar, usually with some small admixture of white silvery mica, often passes into graphic granite.

Fig. 683.

Fig. 684.

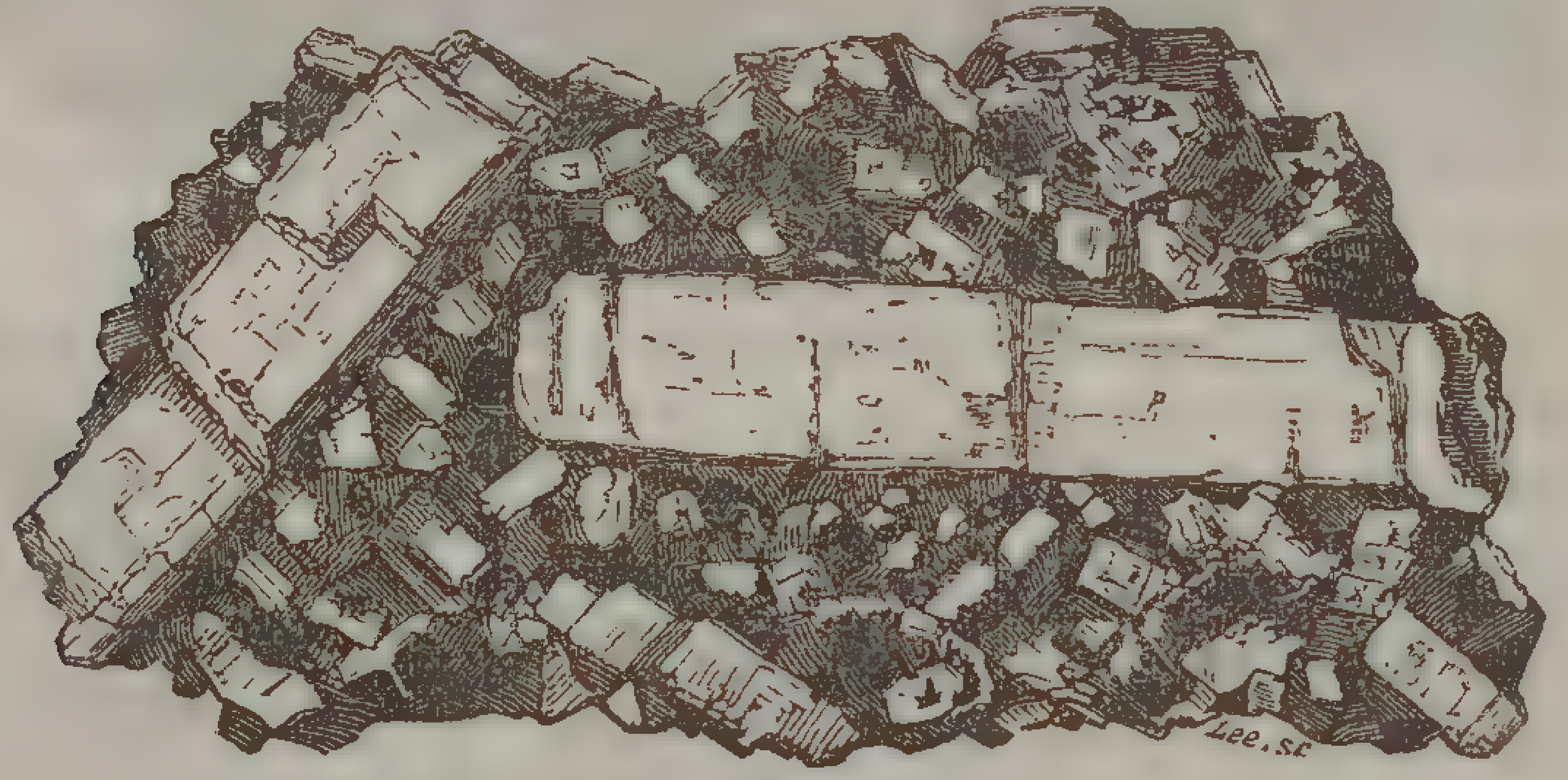
Graphic granite.
Fig. 683. Section parallel to the laminæ.
Fig. 684. Section transverse to the laminæ.

As a general rule, quartz, in a compact or amorphous state, forms a vitreous mass, serving as the base in which felspar and mica have crystallized; for although these minerals are much more fusible than silex, they have often imprinted their shapes upon the quartz. This fact, apparently so paradoxical, has given rise to much ingenious speculation. We should naturally have anticipated that, during the cooling of the mass, the flinty portion would be the first to consolidate; and that the different varieties of felspar, as well as garnets and tourmalines, being more easily liquefied by heat, would be the last. Precisely the reverse has taken place in the passage of most granite aggregates from a fluid to a solid state, crystals of the more fusible minerals being found enveloped in hard, transparent, glassy quartz, which has often taken very faithful casts of each, so as to preserve even the microscopically minute striations on the surface of prisms of tourmaline. Various explanations of this phenomenon have been proposed by MM. de Beaumont, Fournet, and Durocher. They refer to M. Guadin's experiments on the fusion of quartz, which show that silex, as it cools, has the property of remaining in a viscous state, whereas alumina never does. This "gelatinous flint" is supposed to retain a considerable degree of plasticity long after the granitic mixture has acquired a low temperature; and M. E. de Beaumont suggests that electric action may prolong the duration of the viscosity of silex. Occasionally, however, we find the quartz and felspar mutually imprinting their forms on each other, affording evidence of the simultaneous crystallization of both.*

It may here be remarked that ordinary granite, as well as syenite and eurite, usually contains two kinds of felspar, 1st, the common, or orthoclase, in which potash is the prevailing alkali, and this generally occurs in large crystals of a white or flesh colour; and 2ndly, felspar in smaller crystals, in which soda predominates, usually of a dead white or spotted, and striated lake albite, but not the same in composition.†

Porphyritic granite.—This name has been sometimes given to that variety in which large crystals of common felspar, sometimes more than 3 inches in length, are scattered through an ordinary base of granite. An example of this texture may be seen in the granite of the Land's End, in Cornwall (fig. 685.). The two larger prismatic crystals in this drawing represent felspar, smaller crystals of which

Fig. 685.



Porphyritic granite. Land's End, Cornwall.

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* Bulletin, 2d sèrie, iv. 1304.; and Archiac, Hist. des Progrès de Geol., i. 38.

† Delesse, Ann. des Mines, 1852, t. iii. p. 409., and 1848. t. xiii. p. 675.

are also seen, similar in form, scattered through the base. In this base also appear black specks of mica, the crystals of which have a more or less perfect hexagonal outline. The remainder of the mass is quartz, the translucency of which is strongly contrasted to the opaqueness of the white felspar and black mica. But neither the transparency of the quartz nor the silvery lustre of the mica can be expressed in the engraving.

The uniform mineral character of large masses of granite seems to indicate that large quantities of the component elements were thoroughly mixed up together, and then crystallized under precisely similar conditions. There are, however, many accidental, or "occasional," minerals, as they are termed, which belong to granite. Among these black schorl or tourmaline, actinolite, zircon, garnet, and fluor spar are not uncommon; but they are too sparingly dispersed to modify the general aspect of the rock. They show, nevertheless, that the ingredients were not everywhere exactly the same; and a still greater variation may be traced in the ever-varying proportions of the felspar, quartz, and mica.

Syenite. — When hornblende is the substitute for mica, which is very commonly the case, the rock becomes Syenite: so called from the celebrated ancient quarries of Syene in Egypt. It has all the appearance of ordinary granite, except when mineralogically examined in hand specimens, and is fully entitled to rank as a geological member of the same plutonic family as granite. Syenite, however, after maintaining the granitic character throughout extensive regions, is not uncommonly found to lose its quartz, and to pass insensibly into syenitic greenstone, a rock of the trap family. Werner considered syenite as a binary compound of felspar and hornblende, and regarded quartz as merely one of its occasional minerals.

Syenitic granite. — The quadruple compound of quartz, felspar, mica, and hornblende, may be so termed. This rock occurs in Scotland and in Guernsey.

Talcose granite, or Protogine of the French, is a mixture of felspar, quartz, and talc. It abounds in the Alps, and in some parts of Cornwall, producing by its decomposition the china clay, more than 12,000 tons of which are annually exported from that country for the potteries.*

Schorl rock, and schorly granite. — The former of these is an aggregate of schorl, or tourmaline, and quartz. When felspar and mica are also present, it may be called schorly granite. This kind of granite is comparatively rare.

Eurite. — A rock in which all the ingredients of granite are blended into a finely granular mass. When crystalline, it is seen to contain crystals of quartz, mica, common felspar, and soda felspar. When there is no mica, and when common felspar predominates, so as to give it a white colour, it becomes a felspathic granite, called

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* Boase on Primary Geology, p. 16.

"whitestone" (Weisstein) by Werner, or *Leptynite* by the French, in which microscopic crystals of garnet are often present.

All these and other varieties of granite pass into certain kinds of trap, a circumstance which affords one of many arguments in favour of what is now the prevailing opinion, that the granites are also of igneous origin. The contrast of the most crystalline form of granite to that of the most common and earthy trap is undoubtedly great; but each member of the volcanic class is capable of becoming porphyritic, and the base of the porphyry may be more and more crystalline, until the mass passes to the kind of granite most nearly allied in mineral composition.

The minerals which constitute alike the granitic and volcanic rocks consist, almost exclusively, of seven elements, namely, silica, alumina, magnesia, lime, soda, potash, and iron (see Table, p. 479.); and these may sometimes exist in about the same proportions in a porous lava, a compact trap, or a crystalline granite. It may perhaps be found, on farther examination — for on this subject we have yet much to learn — that the presence of these elements in certain proportions is more favourable than in others to their assuming a crystalline or true granitic structure; but it is also ascertained by experiment, that the same materials may, under different circumstances, form very different rocks. The same lava, for example, may be glassy, or scoriaceous, or stony, or porphyritic, according to the more or less rapid rate at which it cools; and some trachytes and syenitic-greenstones may doubtless form granite and syenite, if the crystallization take place slowly.

It has also been suggested that the peculiar nature and structure of granite may be due to its retaining in it that water which is seen to escape from lavas when they cool slowly, and consolidate in the atmosphere. Boutigny's experiments have shown that melted matter, at a white heat, requires to have its temperature lowered before it can vapourize water; and such discoveries, if they fail to explain the manner in which granites have been formed, serve at least to remind us of the entire distinctness of the conditions under which plutonic and volcanic rocks must be produced.*

It would be easy to multiply examples and authorities to prove the gradation of the granitic into the trap rocks. On the western side of the fiord of Christiania, in Norway, there is a large district of trap, chiefly greenstone-porphyry and syenitic-greenstone, resting on fossiliferous strata. To this, on its southern limit, succeeds a region equally extensive of syenite, the passage from the volcanic to the plutonic rock being so gradual that it is impossible to draw a line of demarcation between them.

"The ordinary granite of Aberdeenshire," says Dr. MacCulloch, "is the usual ternary compound of quartz, felspar, and mica; but sometimes hornblende is substituted for the mica. But in many places a variety occurs which is composed simply of felspar and

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* E. de Beaumont, Bulletin, vol. iv., 2d ser., pp. 1318. and 1320.

hornblende; and in examining more minutely this duplicate compound, it is observed in some places to assume a fine grain, and at length to become undistinguishable from the greenstones of the trap family. It also passes in the same uninterrupted manner into a basalt, and at length into a soft claystone, with a schistose tendency on exposure, in no respect differing from those of the trap islands of the western coast." The same author mentions, that in Shetland a granite composed of hornblende, mica, felspar, and quartz graduates in an equally perfect manner into basalt.*

In Hungary there are varieties of trachyte, which, geologically speaking, are of modern origin, in which crystals, not only of mica, but of quartz, are common, together with felspar and hornblende. It is easy to conceive how such volcanic masses may, at a certain depth from the surface, pass downwards into granite.

I have already hinted at the close analogy in the forms of certain granitic and trappean veins; and it will be found that strata penetrated by plutonic rocks have suffered changes very similar to those exhibited near the contact of volcanic dikes. Thus, in Glen Tilt, in Scotland, alternating strata of limestone and argillaceous schist come in contact with a mass of granite. The contact does not take place as might have been looked for, if the granite had been formed there before the strata were deposited, in which case the section would have appeared as in fig. 686.; but the union is as represented in fig. 687., the undulating outline of the granite intersecting different strata, and occasionally intruding itself in tortuous veins into the beds of clay-slate and limestone, from which it differs so remarkably in composition. The limestone is sometimes changed in character by the proximity of the granitic mass or its veins, and acquires a more compact texture, like that of hornstone or chert, with a splintery fracture, and effervescing feebly with acids.

Fig. 686.

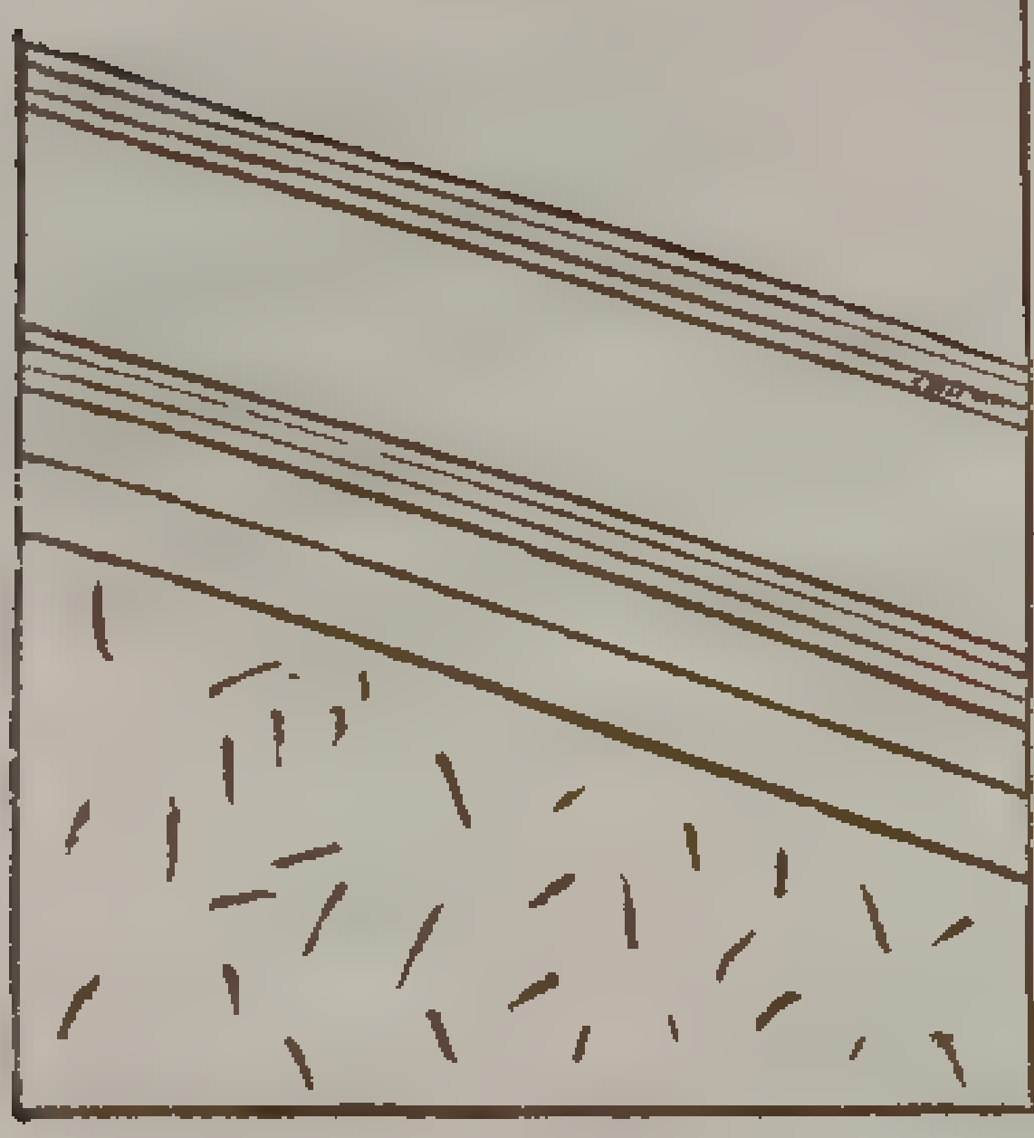
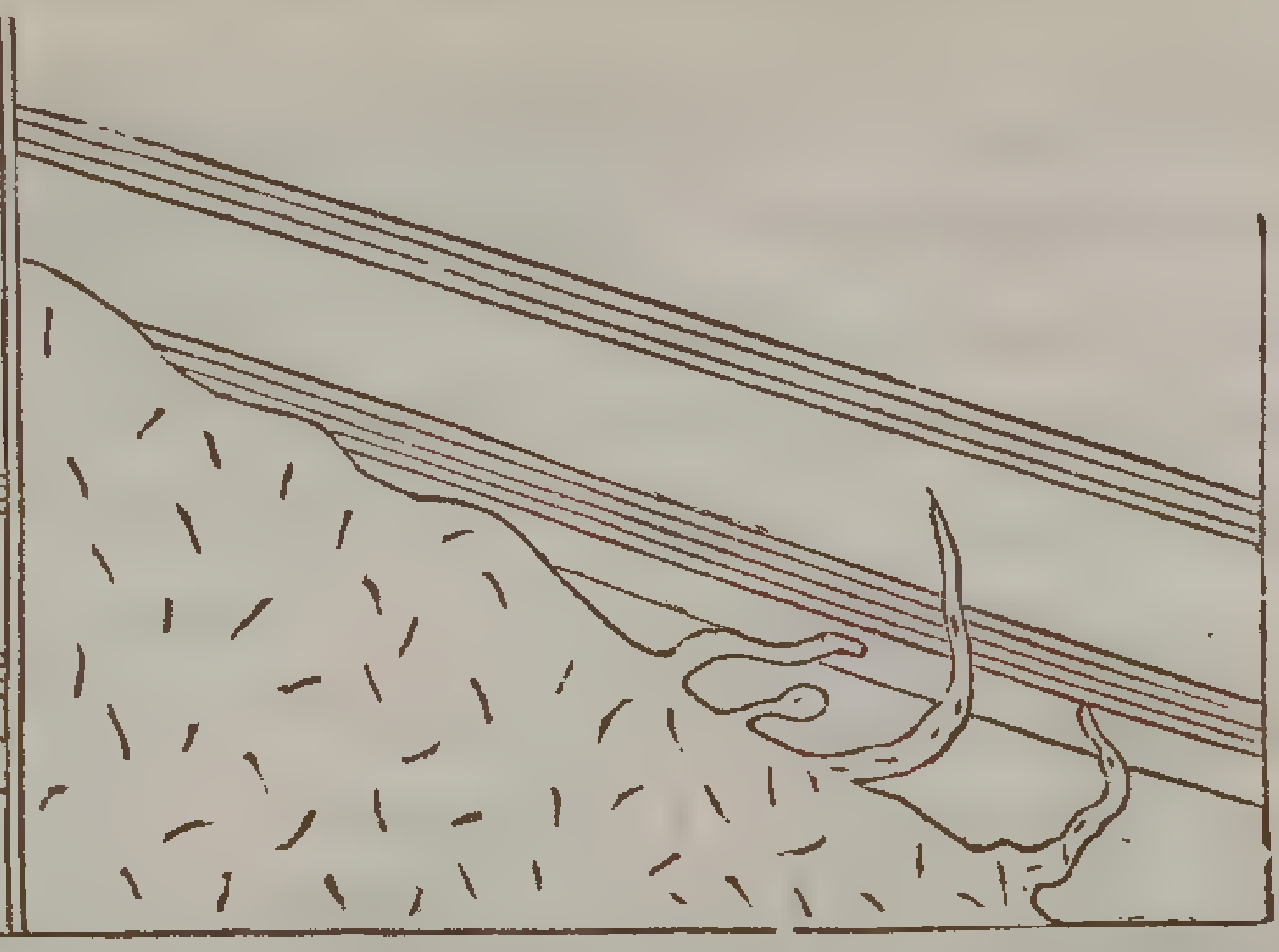


Fig. 687.



Junction of granite and argillaceous schist in Glen Tilt. (Mac Culloch.)†

The annexed diagram (fig. 688.) represents another junction, in the same district, where the granite sends forth so many veins as to reticulate the limestone and schist, the veins diminishing towards

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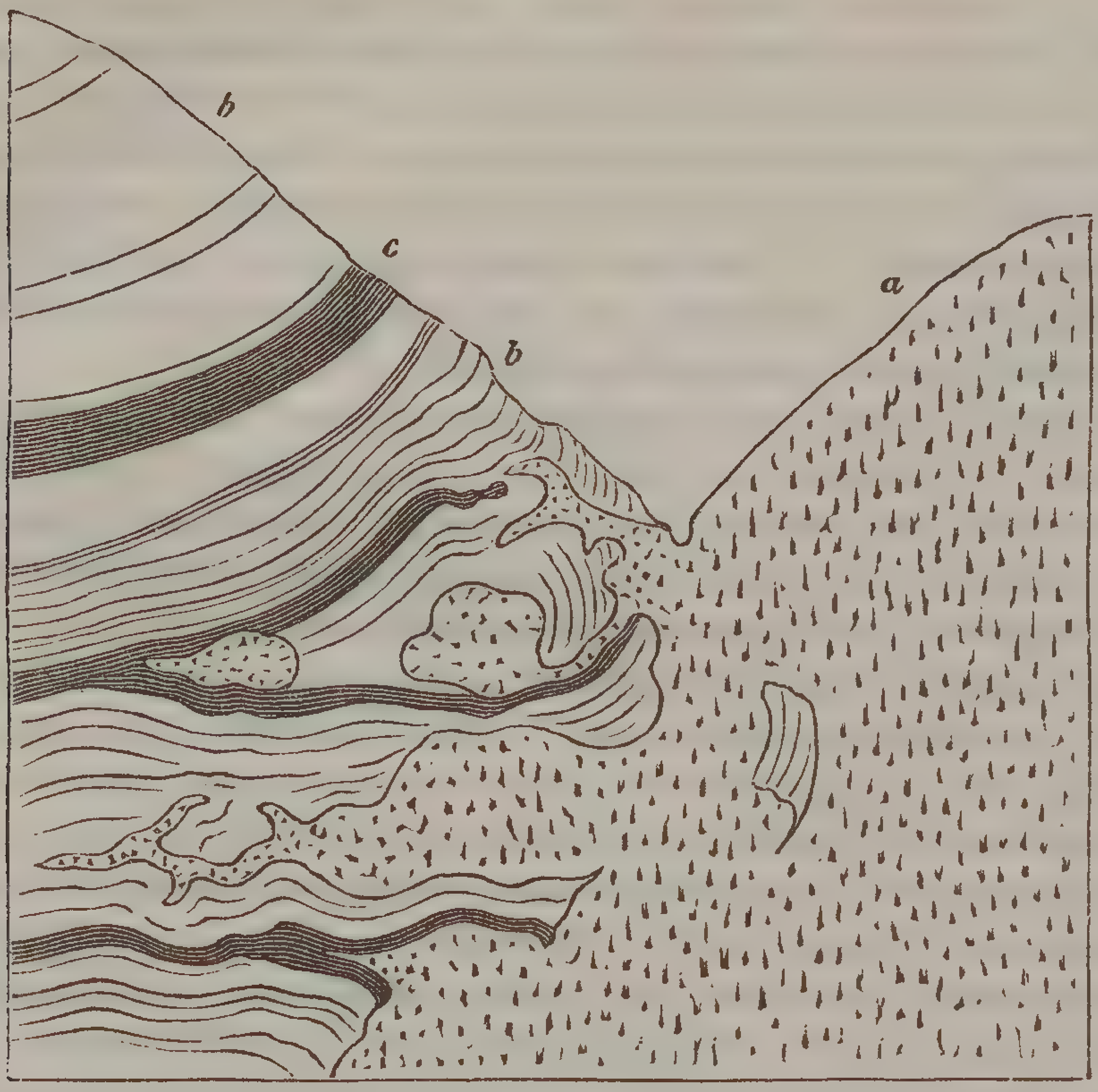
[*] Syst. of Geol. vol. i. p. 157. and 158.

[†] Geol. Trans., 1st series, vol. iii. pl. 21.

Fig. 688.



Junction of granite and limestone in Glen Tilt. (MacCulloch.)
a. Granite. *b.* Limestone.
c. Blue argillaceous schist.

their termination to the thickness of a leaf of paper or a thread. In some places fragments of granite appear entangled, as it were, in the limestone, and are not visibly connected with any larger mass; while sometimes, on the other hand, a lump of the limestone is found in the midst of the granite. The ordinary colour of the limestone of Glen Tilt is lead blue, and its texture large-grained and highly crystalline; but where it approximates to the granite, particularly where it is penetrated by the smaller veins, the crystalline texture disappears, and it assumes an appearance exactly resembling that of hornstone. The associated argillaceous schist often passes into hornblende slate, where it approaches very near to the granite.*

The conversion of the limestone in these and many other instances into a siliceous rock, effervescing slowly with acids, would be difficult of explanation, were it not ascertained that such limestones are always impure, containing grains of quartz, mica, or felspar disseminated through them. The elements of these minerals, when the rock has been subjected to great heat, may have been fused, and so spread more uniformly through the whole mass.

In the plutonic, as in the volcanic rocks, there is every gradation from a tortuous vein to the most regular form of a dike, such as intersect the tuffs and lavas of Vesuvius and Etna. Dikes of granite may be seen, among other places, on the southern flank of

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* MacCulloch. Geol. Trans., vol. iii. p. 259.

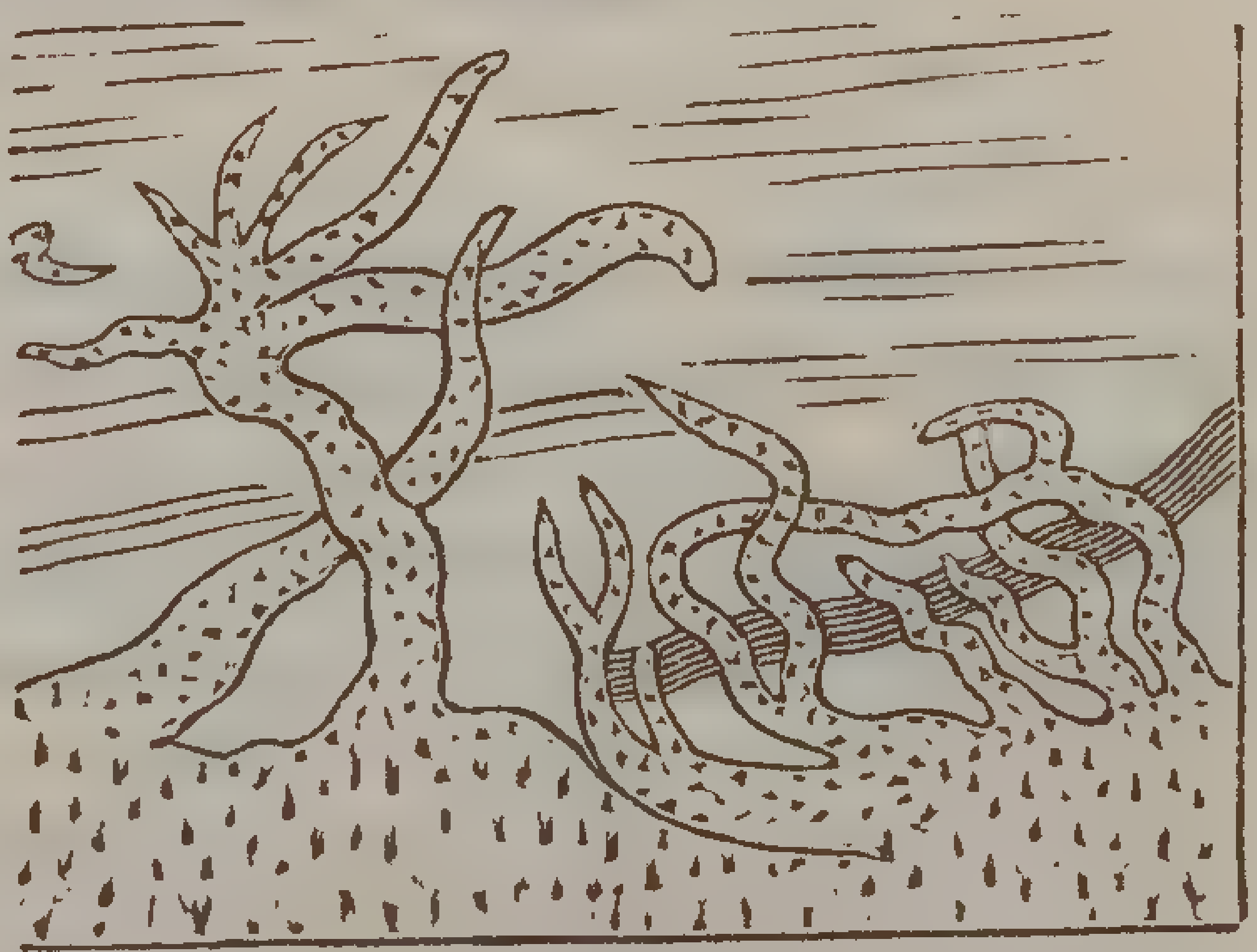
Mount Battock, one of the Grampians, the opposite walls sometimes preserving an exact parallelism for a considerable distance.

As a general rule, however, granite veins in all quarters of the globe are more sinuous in their course than those of trap. They present similar shapes at the most northern point of Scotland, and the southernmost extremity of Africa, as the annexed drawings will show.

Fig. 689.

Granite veins traversing clay slate, Table Mountain, Cape of Good Hope.*

Fig. 690.



Granite veins traversing gneiss, Cape Wrath. (Mac Culloch.) †

It is not uncommon for one set of granite veins to intersect another; and sometimes there are three sets, as in the environs of Heidelberg, where the granite on the banks of the river Necker is seen to consist of three varieties, differing in colour, grain, and various peculiarities of mineral composition. One of these, which is evidently the second in age, is seen to cut through an older granite; and another, still newer, traverses both the second and the first.

In Shetland there are two kinds of granite. One of them, composed of hornblende, mica, felspar, and quartz, is of a dark colour, and is seen underlying gneiss. The other is a red granite, which penetrates the dark variety everywhere in veins.‡

The accompanying sketches will explain the manner in which granite veins often ramify and cut each other (figs. 690. and 691.). They represent the manner in which the gneiss at Cape Wrath, in Sutherlandshire, is intersected by veins. Their light colour, strongly contrasted with that of the hornblende-schist, here associated with the gneiss, renders them very conspicuous.

Granite very generally assumes a finer grain, and undergoes a change in mineral composition, in the veins which it sends into contiguous rocks. Thus, according to Professor Sedgwick, the main body of the Cornish granite is an aggregate of mica, quartz, and felspar; but the veins are sometimes without mica, being a granular aggregate of quartz and felspar. In other varieties quartz

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* Capt. B. Hall, Trans. Roy. Soc. Edin., vol. vii.

† Western Islands, pl. 31.

‡ MacCulloch, Syst. of Geol., vol. i p. 58.

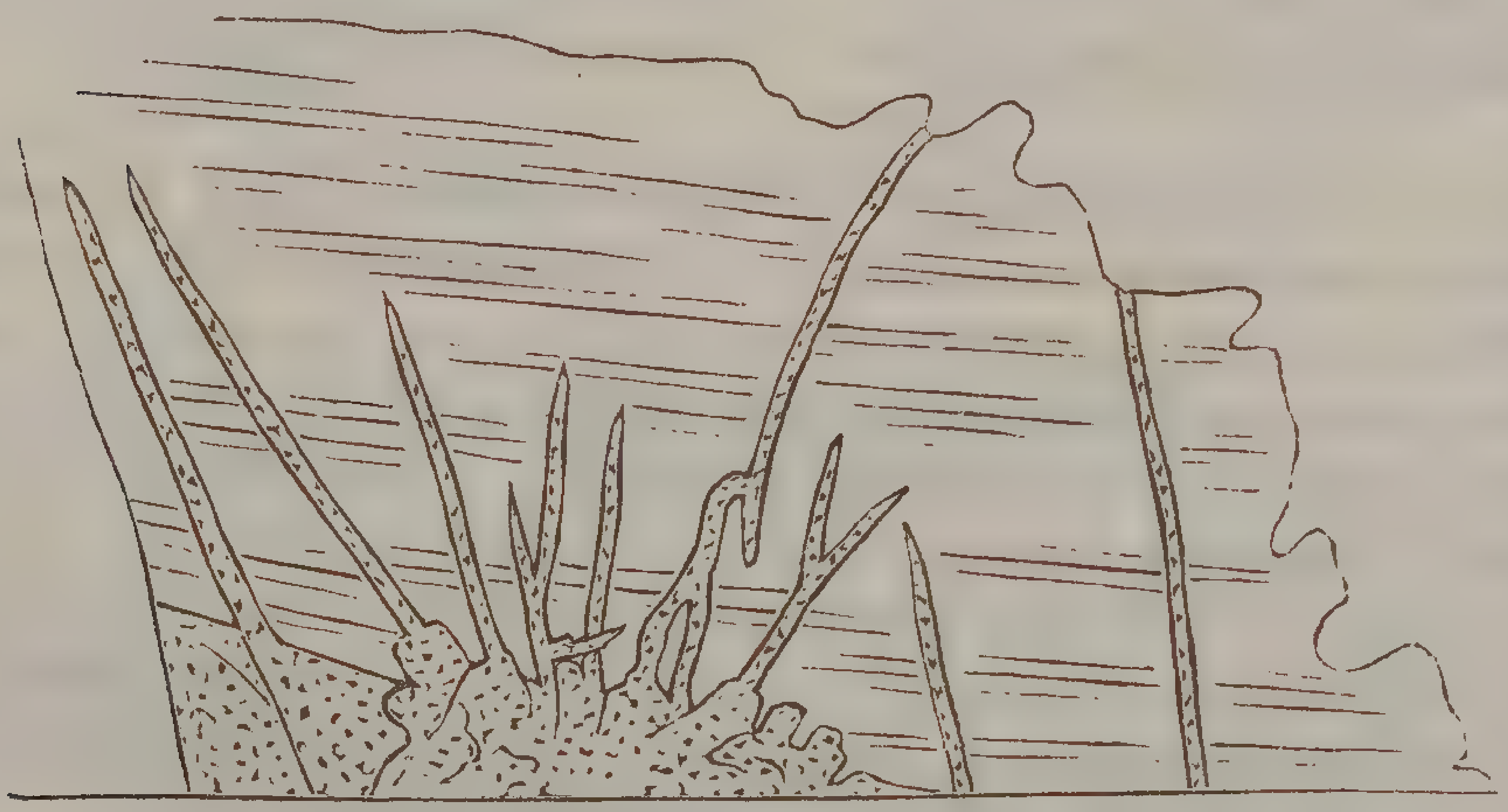
Fig. 691.

Granite veins traversing gneiss at Cape Wrath, in Scotland. (MacCulloch.)

prevails to the almost entire exclusion both of felspar and mica; in others, the mica and quartz both disappear, and the vein is simply composed of white granular felspar.*

Fig. 692. is a sketch of a group of granite veins in Cornwall, given by Messrs. Von Oeynhausen and Von Dechen.† The main body of the granite here is of a porphyritic appearance, with large crystals of felspar; but in the veins it is fine-grained, and without these large crystals. The general height of the veins is from 16 to 20 feet, but some are much higher.

Fig. 692.



Granite veins passing through hornblende slate, Carnsilver Cove, Cornwall.

In the Valorsine, a valley not far from Mont Blanc in Switzerland, an ordinary granite, consisting of felspar, quartz, and mica, sends forth veins into a talcose gneiss (or stratified protogine), and in some places lateral ramifications are thrown off from the principal veins at right angles (see fig. 693.), the veins, especially the minute ones, being finer grained than the granite in mass.

It is here remarked, that the schist and granite, as they approach, seem to exercise a reciprocal influence on each other, for both

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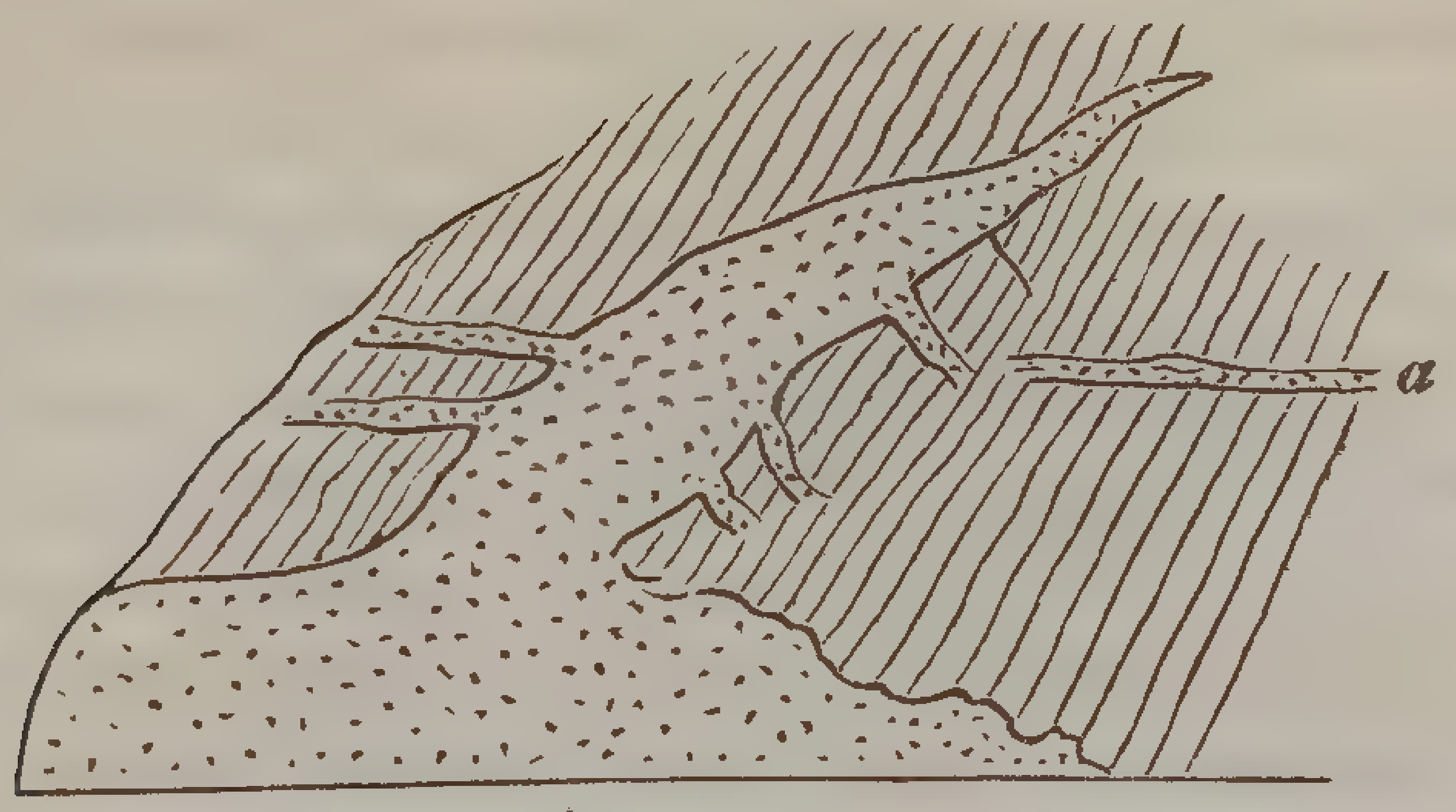
* On Geol. of Cornwall, Camb. Trans. vol. i. p. 124.

† Phil. Mag. and Annals, No. 27. new series, March, 1829.

Fig. 693.



Veins of granite in talcose gneiss. (L. A. Necker.)

undergo a modification of mineral character. The granite, still remaining unstratified, becomes charged with green particles; and the talcose gneiss assumes a granitiform structure without losing its stratification.*

Professor Keilhau drew my attention to several localities in the country near Christiania, where the mineral character of gneiss appears to have been affected by a granite of much newer origin, for some distance from the point of contact. The gneiss, without losing its laminated structure, seems to have become charged with a larger quantity of felspar, and that of a redder colour, than the felspar usually belonging to the gneiss of Norway.

Granite, syenite, and those porphyries which have a granitiform structure, in short all plutonic rocks, are frequently observed to contain metals, at or near their junction with stratified formations. On the other hand, the veins which traverse stratified rocks are, as a general law, more metalliferous near such junctions than in other positions. Hence it has been inferred that these metals may have been spread in a gaseous form through the fused mass, and that the contact of another rock, in a different state of temperature, or sometimes the existence of rents in other rocks in the vicinity, may have caused the sublimation of the metals.†

There are many instances, as at Markerud, near Christiania, in Norway, where the strike of the beds has not been deranged throughout a large area by the intrusion of granite, both in large masses and in veins. This fact is considered by some geologists to militate against the theory of the forcible injection of granite in a fluid state. But it may be stated in reply, that ramifying dikes of trap also, which almost all now admit to have been once fluid, pass through the same fossiliferous strata, near Christiania, without deranging their strike or dip.‡

The real or apparent isolation of large or small masses of granite detached from the main body, as at *a*, *b*, fig. 694., and above, fig. 688., and *a*, fig. 693., has been thought by some writers to be irre-

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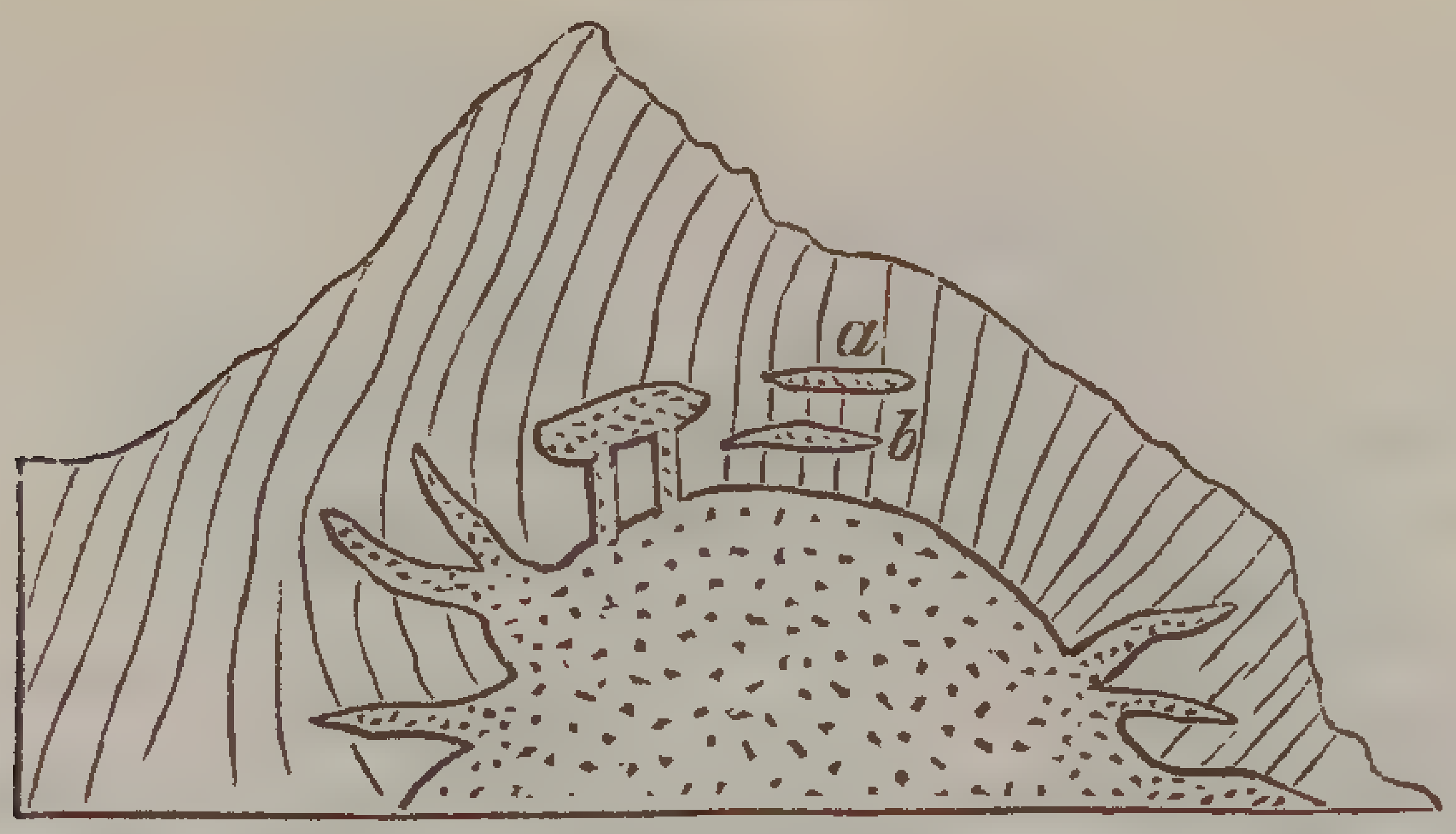
* Necker, sur la Val. de Valorsine, Mém. de la Soc. de Phys. de Génève, 1828. I visited, in 1832, the spot referred to in fig. 693.

† Necker, Proceedings of Geol. Soc. No. 26. p. 392.

‡ See Keilhau's Gæa Norvegica; Christiania, 1838.

Fig. 694.

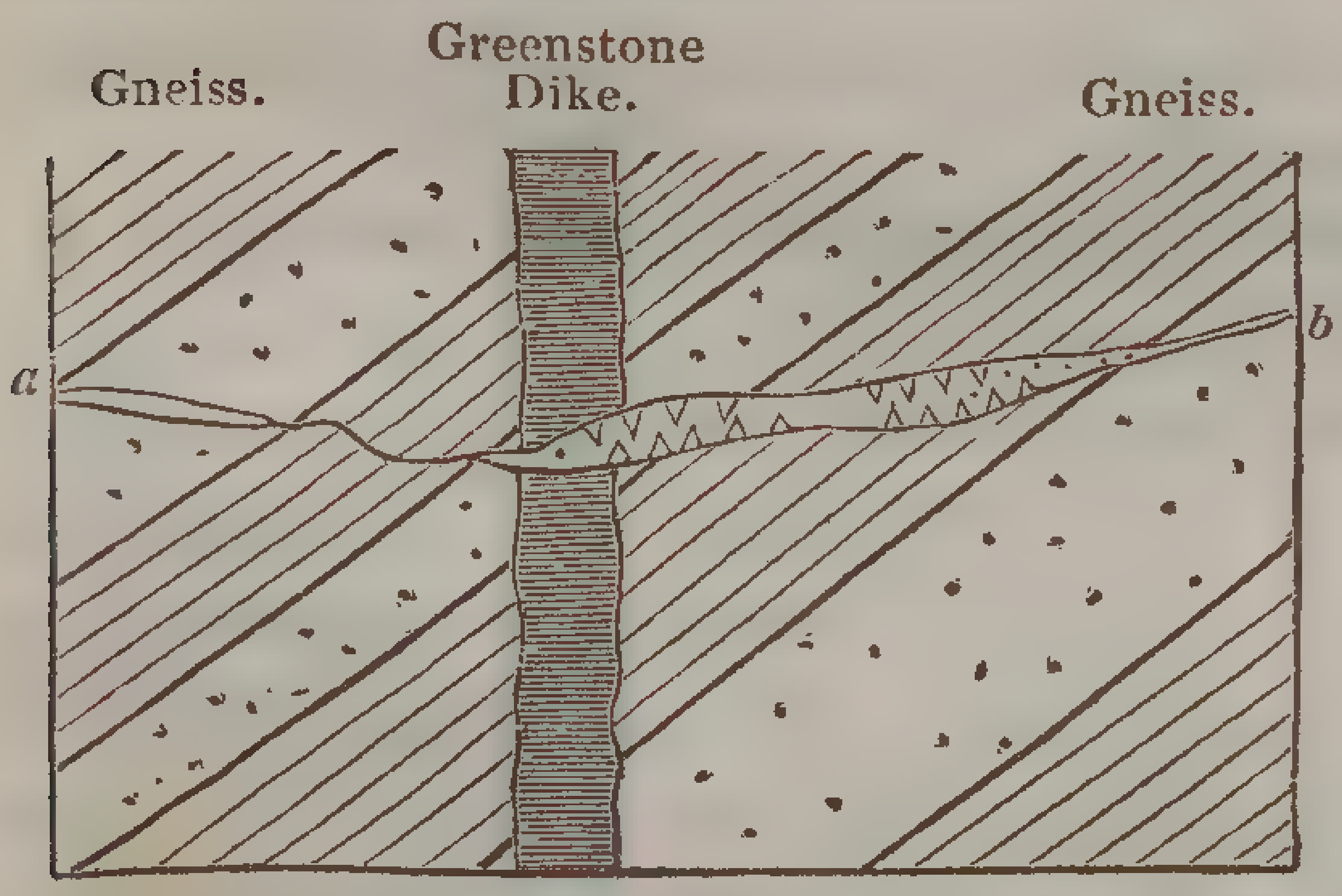


General view of junction of granite and schist of the Valorsine. (L. A. Necker.)

concilable with the doctrine usually taught respecting veins; but many of them may, in fact, be sections of root-shaped prolongations of granite; while, in other cases, they may in reality be detached portions of rock having the plutonic structure. For there may have been spots in the midst of the invaded strata, in which there was an assemblage of materials more fusible than the rest, or more fitted to combine readily into some form of granite.

Veins of pure quartz are often found in granite as in many stratified rocks, but they are not traceable, like veins of granite or trap, to large bodies of rock of similar composition. They appear to have been cracks, into which siliceous matter was infiltered. Such segregation, as it is called, can sometimes be shown to have clearly taken place long subsequently to the original consolidation of the containing rock. Thus, for example, I observed in the gneiss of Tronstad Strand, near Drammen, in Norway, the annexed section on the beach. It appears that the alternating strata of whitish granitiform gneiss and black hornblende-schist were first cut through by a greenstone dike, about 2½ feet wide; then the crack *a b* passed through all these rocks, and was filled up with quartz. The opposite walls of the vein are in some parts incrusted with transparent crystals of quartz, the middle of the vein being filled up with common opaque white quartz.

Fig. 695.



a, b. Quartz vein passing through gneiss and greenstone, Tronstad Strand, near Christiania.

We have seen that the volcanic formations have been called overlying, because they not only penetrate others but spread over them. Mr. Necker has proposed to call the granites the underlying igneous rocks, and the distinction here indicated is highly characteristic. It was indeed supposed by some of the earlier observers, that the granite of Christiania, in Norway, was intercalated in mountain masses between the primary or paleozoic strata of that country, so as to overlie fossiliferous shale and limestone. But although the granite sends veins into these fossiliferous rocks, and is decidedly posterior in origin, its actual superposition in mass has been disproved by Professor Keilhau, whose observations on this controverted point I had opportunities in 1837 of verifying. There are, however, on a smaller scale, certain beds of euritic porphyry, some a few feet, others many yards in thickness, which pass into granite, and deserve perhaps to be classed as plutonic rather than trappean rocks, which may truly be described as interposed conformably between fossiliferous strata, as the porphyries (*a*, *c*, fig. 696.), which divide the bituminous shales and argillaceous limestones, *f f*. But some of these same porphyries are partially unconformable, as *b*, and may lead us to suspect that the others also, notwithstanding their appearance of interstratification, have been forcibly injected. Some of the porphyritic rocks above mentioned are highly quartzose, others very felspathic. In proportion as the masses are more voluminous, they become more granitic in their texture, less conformable, and even begin to send forth veins into contiguous strata. In a word, we have here a beautiful illustration of the intermediate gradations between volcanic and plutonic rocks, not only in their mineralogical composition and structure, but also in their relations of position to associated formations. If the term overlying can in this instance be applied to a plutonic rock, it is only in proportion as that rock begins to acquire a trappean aspect.

Fig. 696.

Euritic porphyry alternating with primary fossiliferous strata, near Christiania.

It has been already hinted that the heat, which in every active volcano extends downwards to indefinite depths, must produce simultaneously very different effects near the surface and far below it; and we cannot suppose that rocks resulting from the crystallizing of fused matter under a pressure of several thousand feet, much less miles, of the earth's crust can resemble those formed at or near the surface. Hence the production at great depths of a class of rocks analogous to the volcanic, and yet differing in many particulars, might also have been predicted, even had we no plutonic formations to account for. How well these agree, both in their positive and negative characters, with the theory of their deep subterranean origin, the student will be able to judge by considering the descriptions already given.

It has, however, been objected, that if the granitic and volcanic rocks were simply different parts of one great series, we ought to find in mountain chains volcanic dikes passing upwards into lava and downwards into granite. But we may answer that our vertical sections are usually of small extent; and if we find in certain places a transition from trap to porous lava, and in others a passage from granite to trap, it is as much as could be expected of this evidence.

The prodigious extent of denudation which has been already demonstrated to have occurred at former periods, will reconcile the student to the belief that crystalline rocks of high antiquity, although deep in the earth's crust when originally formed, may have become uncovered and exposed at the surface. Their actual elevation above the sea may be referred to the same causes to which we have attributed the upheaval of marine strata, even to the summits of some mountain chains. But to these and other topics, I shall revert when speaking, in the next chapter, of the relative ages of different masses of granite.

CHAPTER XXXIV.

ON THE DIFFERENT AGES OF THE PLUTONIC ROCKS.

Difficulty in ascertaining the precise age of a plutonic rock—Test of age by relative position—Test by intrusion and alteration—Test by mineral composition—Test by included fragments—Recent and Pliocene plutonic rocks, why invisible—Tertiary plutonic rocks in the Andes—Granite altering Cretaceous rocks—Granite altering Lias in the Alps and in Skye—Granite of Dartmoor altering Carboniferous strata—Granite of the Old Red Sandstone period—Syenite altering Silurian strata in Norway—Blending of the same with gneiss—Most ancient plutonic rocks—Granite protruded in a solid form—On the probable age of the granites of Arran, in Scotland.

WHEN we adopt the igneous theory of granite, as explained in the last chapter, and believe that different plutonic rocks have originated at successive periods beneath the surface of the planet, we must be prepared to encounter greater difficulty in ascertaining the precise age of such rocks, than in the case of volcanic and fossiliferous formations. We must bear in mind, that the evidence of the age of each contemporaneous volcanic rock was derived, either from lavas poured out upon the ancient surface, whether in the sea or in the atmosphere, or from tuffs and conglomerates, also deposited at the surface, and either containing organic remains themselves, or intercalated between strata containing fossils. But all these tests fail when we endeavour to fix the chronology of a rock which has crystallized from a state of fusion in the bowels of the earth. In that case, we are reduced to the following tests: 1st, relative position; 2dly, intrusion, and alteration of the rocks in contact; 3dly, mineral characters; 4thly, included fragments.

Test of age by relative position.—Unaltered fossiliferous strata of every age are met with reposing immediately on plutonic rocks; as at Christiania, in Norway, where the Newer Pliocene deposits rest on granite; in Auvergne, where the freshwater Eocene strata, and at Heidelberg, on the Rhine, where the New Red sandstone occupy a similar place. In all these, and similar instances, inferiority in position is connected with the superior antiquity of granite. The crystalline rock was solid before the sedimentary beds were superimposed, and the latter usually contain in them rounded pebbles of the subjacent granite.

Test by intrusion and alteration.—But when plutonic rocks send veins into strata, and alter them near the point of contact, in the manner before described (p. 571.), it is clear that, like intrusive traps, they are newer than the strata which they invade and alter. Examples of the application of this test will be given in the sequel.

Test by mineral composition.—Notwithstanding a general uniformity in the aspect of plutonic rocks, we have seen in the last chapter that there are many varieties, such as Syenite, Talcose granite, and others. One of these varieties is sometimes found exclusively prevailing throughout an extensive region, where it preserves a homogeneous character; so that, having ascertained its relative age in one place, we can easily recognize its identity in others, and thus determine from a single section the chronological relations of large mountain masses. Having observed, for example, that the syenitic granite of Norway, in which the mineral called zircon abounds, has altered the Silurian strata wherever it is in contact, we do not hesitate to refer other masses of the same zircon-syenite in the south of Norway to the same era.

Some have imagined that the age of different granites might, to a great extent, be determined by their mineral characters alone; syenite, for instance, or granite with hornblende, being more modern than common or micaceous granite. But modern investigations have proved these generalizations to have been premature. The syenitic granite of Norway already alluded to may be of the same age as the Silurian strata, which it traverses and alters, or may belong to the Old Red sandstone period; whereas the granite of Dartmoor, although consisting of mica, quartz, and felspar, is newer than the coal. (See p. 586.).

Test by included fragments.—This criterion can rarely be of much importance, because the fragments involved in granite are usually so much altered, that they cannot be referred with certainty to the rocks whence they were derived. In the White Mountains, in North America, according to Professor Hubbard, a granite vein, traversing granite, contains fragments of slate and trap which must have fallen into the fissure when the fused materials of the vein were injected from below*, and thus the granite is shown to be newer than certain superficial slaty and trappean formations.

Recent and Pliocene plutonic rocks, why invisible.—The explanations already given in the 29th and in the last chapter of the probable relation of the plutonic to the volcanic formations, will naturally lead the reader to infer, that rocks of the one class can never be produced at or near the surface without some members of the other being formed below simultaneously, or soon afterwards. It is not uncommon for lava-streams to require more than ten years to cool in the open air; and where they are of great depth, a much longer period. The melted matter poured from Jorullo, in Mexico, in the year 1759, which accumulated in some places to the height of 550 feet, was found to retain a high temperature half a century after the eruption.† We may conceive, therefore, that great masses of subterranean lava may remain in a red-hot or incandescent state in the volcanic foci for immense periods, and the process of refrigeration may be extremely gradual. Sometimes, indeed, this process may be retarded

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* Silliman's Journ., No. 69. p. 123.

† See "Principles," *Index*, "Jorullo."

for an indefinite period, by the accession of fresh supplies of heat; for we find that the lava in the crater of Stromboli, one of the Lipari Islands, has been in a state of constant ebullition for the last two thousand years; and we may suppose this fluid mass to communicate with some caldron or reservoir of fused matter below. In the Isle of Bourbon, also, where there has been an emission of lava once in every two years for a long period, the lava below can scarcely fail to have been permanently in a state of liquefaction. If then it be a reasonable conjecture, that about 2000 volcanic eruptions occur in the course of every century, either above the waters of the sea or beneath them*, it will follow, that the quantity of plutonic rock generated, or in progress during the Recent epoch, must already have been considerable.

But as the plutonic rocks originate at some depth in the earth's crust, they can only be rendered accessible to human observation, by subsequent upheaval and denudation. Between the period when a plutonic rock crystallizes in the subterranean regions and the era of its protrusion at any single point of the surface, one or two geological periods must usually intervene. Hence, we must not expect to find the Recent or Newer Pliocene granites laid open to view, unless we are prepared to assume that sufficient time has elapsed since the commencement of the Newer Pliocene period for great upheaval and denudation. A plutonic rock, therefore, must, in general, be of considerable antiquity relatively to the fossiliferous and volcanic formations, before it becomes extensively visible. As we know that the upheaval of land has been sometimes accompanied in South America by volcanic eruptions and the emission of lava, we may conceive the more ancient plutonic rocks to be forced upwards to the surface by the newer rocks of the same class formed successively below, — subterposition in the plutonic, like superposition in the sedimentary rocks, being usually characteristic of a newer origin.

In the accompanying diagram (fig. 697.), an attempt is made to show the inverted order in which sedimentary and plutonic formations may occur in the earth's crust.

The oldest plutonic rock, No. I., has been upheaved at successive periods until it has become exposed to view in a mountain-chain. This protrusion of No. I. has been caused by the igneous agency which produced the newer plutonic rocks Nos. II. III. and IV. Part of the primary fossiliferous strata, No. 1., have also been raised to the surface by the same gradual process. It will be observed that the Recent *strata* No. 4. and the Recent *granite* or plutonic rock No. IV. are the most remote from each other in position, although of contemporaneous date. According to this hypothesis, the convulsions of many periods will be required before *Recent* granite, or granite of the human period, will be upraised so as to form the highest ridges and central axes of mountain-chains. During that

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* "Principles," *Index*, "Volcanic Eruptions."

Fig. 697.

Diagram showing the relative position which the plutonic and sedimentary formations of different ages may occupy.

I. Primary plutonic.
II. Secondary plutonic.
III. Tertiary plutonic.
IV. Recent plutonic.

4. Recent strata.
3. Tertiary strata.
2. Secondary strata.
1. Primary fossiliferous strata.

The metamorphic rocks are not indicated in this diagram ; but the student will infer, from what has been said in Chap. XXXII., that some portions of the stratified formations Nos. 1. and 2. invaded by granite will have become metamorphic.

time the *Recent* strata No. 4. might be covered by a great many newer sedimentary formations.

Eocene granite and plutonic rocks.—In a former part of this volume (p. 231.), the great nummulitic formation of the Alps and Pyrenees was referred to the Eocene period, and it follows that those vast movements which have raised fossiliferous rocks from the level of the sea to the height of more than 10,000 feet above its level have taken place since the commencement of the tertiary epoch. Here, therefore, if anywhere, we might expect to find hypogene formations of Eocene date breaking out in the central axis or most disturbed region of the loftiest chain in Europe. Accordingly, in the Swiss Alps, even the *flysch*, or upper portion of the nummulitic series, has been occasionally invaded by plutonic rocks, and converted into crystalline schists of the hypogene class. There can be little doubt that even the talcose granite or gneiss of Mont Blanc itself has been in a fused or pasty state since the *flysch* was deposited at the bottom of the sea; and the question as to its age is not so much whether it be a secondary or tertiary granite or gneiss, as whether it should be assigned to the Eocene or Miocene epoch.

Great upheaving movements have been experienced in the region of the Andes, during the Post-Pliocene period. In some part, therefore, of this chain, we may expect to discover tertiary plutonic rocks laid open to view. What we already know of the structure of the Chilian Andes seems to realize this expectation. In a transverse section, examined by Mr. Darwin, between Valparaiso and Mendoza, the Cordillera was found to consist of two separate and parallel chains, formed of sedimentary rocks of different ages, the strata in both resting on plutonic rocks, by which they have been altered. In the western or oldest range, called the Peuquenes, are black calcareous clay-slates, rising to the height of nearly 14,000 feet above the sea, in which are shells of the genera *Gryphæa*, *Turritella*, *Terebratula*, and *Ammonite*. These rocks are supposed to be of the age of the central parts of the secondary series of Europe. They are penetrated and altered by dikes and mountain masses of a plutonic rock, which has the texture of ordinary granite, but rarely contains quartz, being a compound of albite and hornblende.

The second or eastern chain consists chiefly of sandstones and conglomerates, of vast thickness, the materials of which are derived from the ruins of the western chain. The pebbles of the conglomerates are, for the most part, rounded fragments of the fossiliferous slates before mentioned. The resemblance of the whole series to certain tertiary deposits on the shores of the Pacific, not only in mineral character, but in the imbedded lignite and silicified woods, leads to the conjecture that they also are tertiary. Yet these strata are not only associated with trap rocks and volcanic tuffs, but are also altered by a granite consisting of quartz, felspar, and talc. They are traversed, moreover, by dikes of the same granite, and by numerous veins of iron, copper, arsenic, silver, and gold; all of which can be traced to the underlying granite.* We have, therefore, strong ground to presume that the plutonic rock here exposed on a large scale in the Chilian Andes is of later date than certain tertiary formations.

But the theory adopted in this work of the subterranean origin of the hypogene formations would be untenable, if the supposed fact here alluded to, of the appearance of tertiary granite at the surface was not a rare exception to the general rule. A considerable lapse of time must intervene between the formation of plutonic and metamorphic rocks in the nether regions, and their emergence at the surface. For a long series of subterranean movements must occur before such rocks can be uplifted into the atmosphere or the ocean; and, before they can be rendered visible to man, some strata which previously covered them must usually have been stripped off by denudation.

We know that in the Bay of Baiæ in 1538, in Cutch in 1819, and on several occasions in Peru and Chili, since the commencement of the present century, the permanent upheaval or subsidence of land has been accompanied by the simultaneous emission of lava at one or more points in the same volcanic region. From these and other examples it may be inferred that the rising or sinking of the earth's crust, operations by which sea is converted into land, and land into sea, are a part only of the consequences of subterranean igneous action. It can scarcely be doubted that this action consists, in a great degree, of the baking, and occasionally the liquefaction, of rocks, causing them to assume, in some cases a larger, in others a smaller volume than before the application of heat. It consists also in the generation of gases, and their expansion by heat, and the injection of liquid matter into rents formed in superincumbent rocks. The prodigious scale on which these subterranean causes have operated in Sicily since the deposition of the Newer Pliocene strata will be appreciated, when we remember that throughout half the surface of that island such strata are met with, raised to the height of from 50 to that of 2000 and even 3000 feet above the level of the sea. In the same island also the older rocks which are contiguous to these marine tertiary strata must have undergone, within the same period, a similar amount of upheaval.

The like observations may be extended to nearly the whole of Europe, for, since the commencement of the Eocene period, the entire European area, including some of the central and very lofty portions of the Alps themselves, as I have elsewhere shown†, has, with the exception of a few districts, emerged from the deep to its present altitude; and even those tracts which were already dry land before the Eocene era have almost everywhere acquired additional height. A large amount of subsidence has also occurred during the same period, so that the extent of the subterranean spaces which have

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* Darwin, pp. 390. 406.; second edition, p. 319.

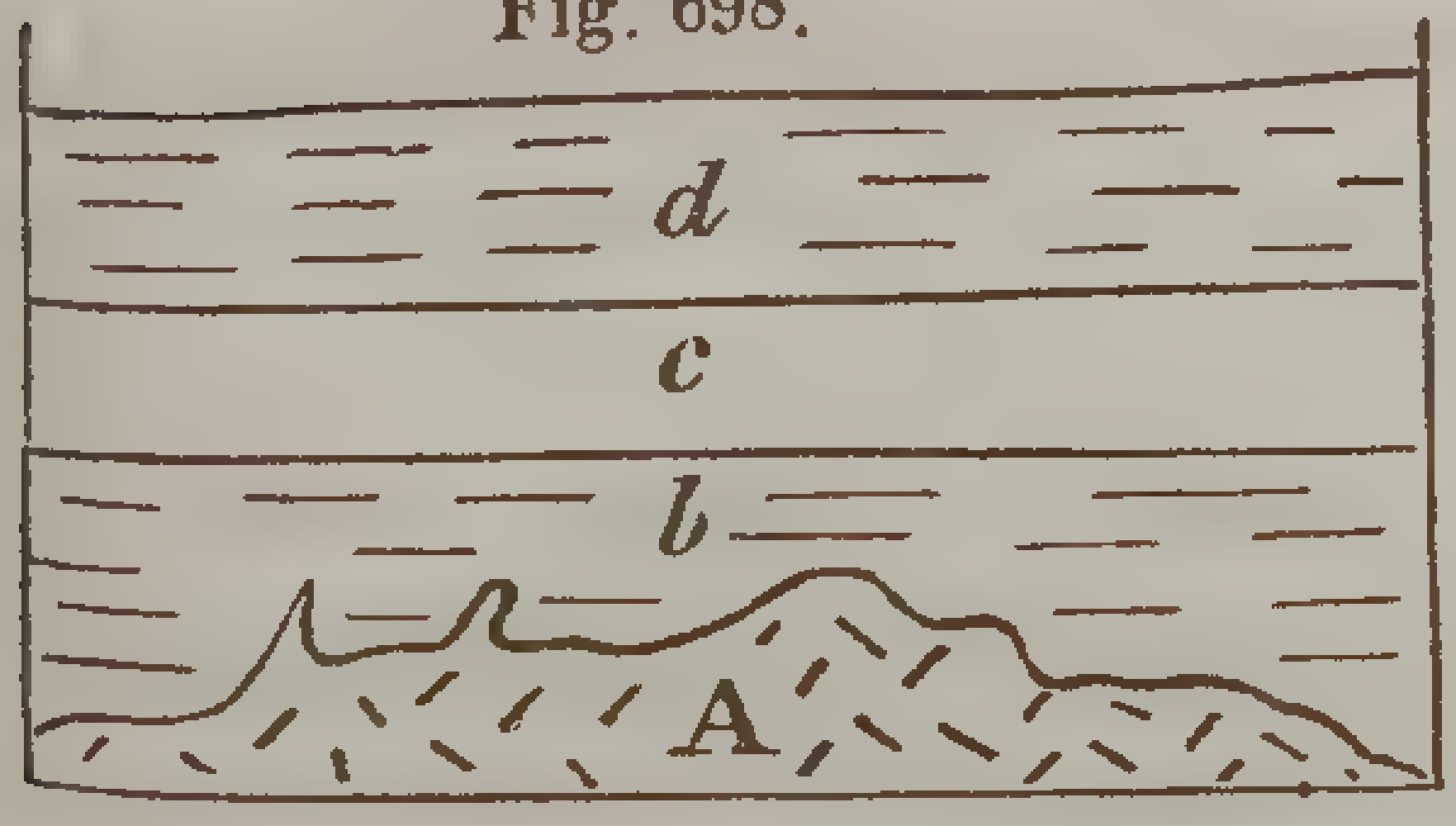
† See map of Europe and explanation, in Principles, book i.

either become the receptacles of sunken fragments of the earth's crust, or have been rendered capable of supporting other fragments at a much greater height than before, must be so great that they probably equal, if not exceed in volume, the entire continent of Europe. We are entitled, therefore, to ask what amount of change of equivalent importance can be proved to have occurred in the earth's crust within an equal quantity of time anterior to the Eocene epoch. They who contend for the more intense energy of subterranean causes in the remoter eras of the earth's history may find it more difficult to give an answer to this question than they anticipated.

The principal effect of volcanic action in the nether regions during the tertiary period seems to have consisted in the upheaval to the surface of hypogene formations of an age anterior to the carboniferous. The repetition of another series of movements, of equal violence, might upraise the plutonic and metamorphic rocks of many secondary periods; and, if the same force should still continue to act, the next convulsions might bring up to the day the *tertiary* and *recent* hypogene rocks. In the course of such changes many of the existing sedimentary strata would suffer greatly by denudation, others might assume a metamorphic structure, or become melted down into plutonic and volcanic rocks. Meanwhile the deposition of a vast thickness of new strata would not fail to take place during the upheaval and partial destruction of the older rocks. But I must refer the reader to the last chapter but one of this volume for a fuller explanation of these views.

Cretaceous period.—It will be shown in the next chapter that chalk, as well as lias, has been altered by granite in the eastern Pyrenees. Whether such granite be cretaceous or tertiary cannot easily be decided. Suppose *b*, *c*, *d*, fig. 698., to be three members of the Cretaceous series, the lowest of which, *b*, has been altered by the granite A, the modifying influence not having extended so far as *c*, or having but slightly affected its lowest beds. Now it can rarely be possible for the geologist to decide whether the beds *d* existed at the time of the intrusion of A, and alteration of *b* and *c*, or whether they were subsequently thrown down upon *c*.

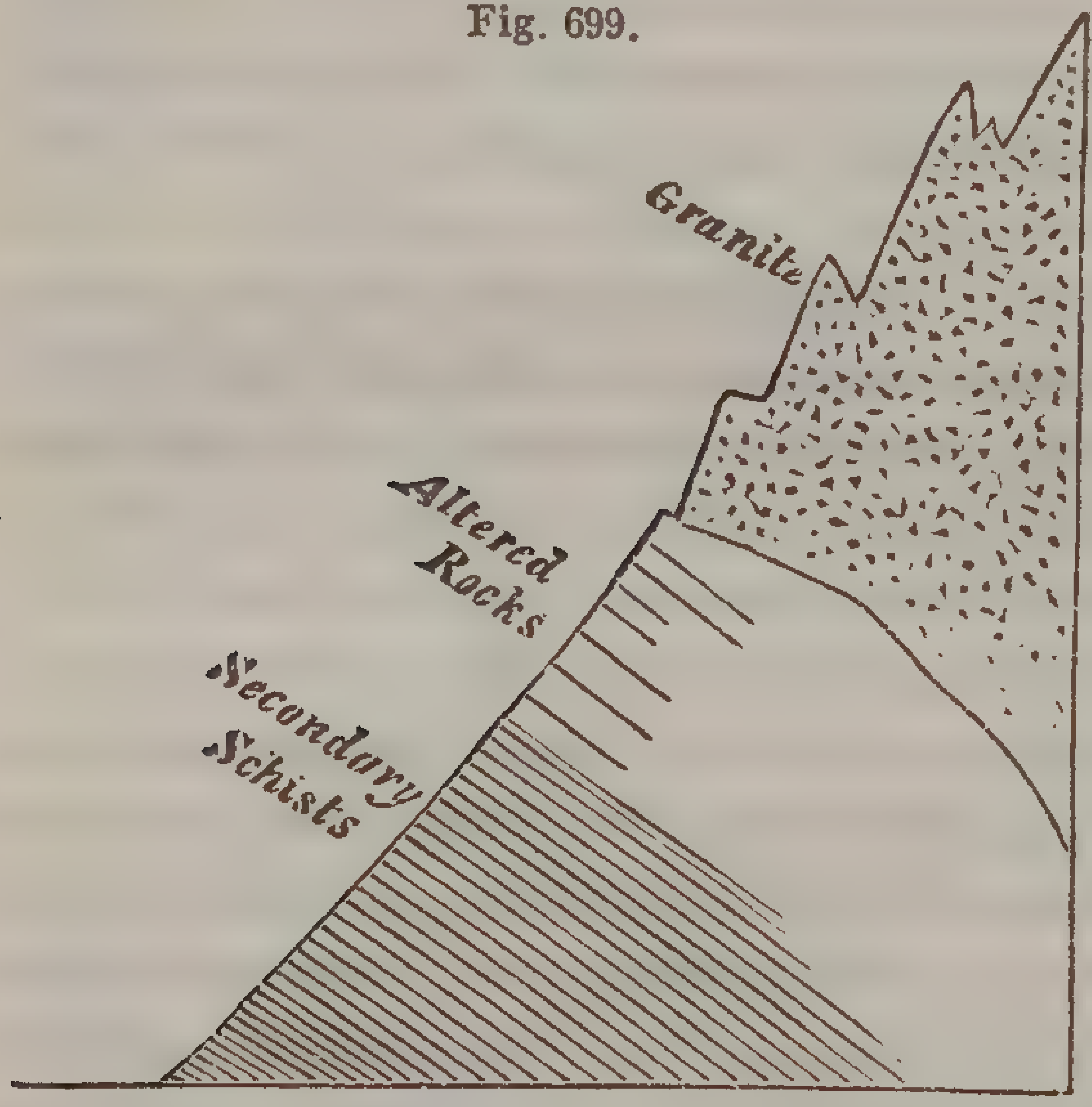
Fig. 698.



But as some Cretaceous and even tertiary rocks have been raised to the height of more than 9000 feet in the Pyrenees, we must not assume that plutonic formations of the same periods may not have been brought up and exposed by denudation, at the height of 2000 or 3000 feet on the flanks of that chain.

Period of Oolite and Lias.—In the department of the Hautes Alpes, in France, near Vizille, M. Elie de Beaumont traced a black argillaceous limestone, charged with belemnites, to within a few yards of a mass of granite. Here the limestone begins to put on a granular texture, but is extremely fine-grained. When nearer the junction it becomes grey, and has a saccharoid structure. In another locality, near Champoleon, a granite composed of quartz, black mica, and rose-coloured felspar is observed partly to overlie the secondary rocks, producing an alteration which extends for about 30 feet downwards, diminishing in the beds which lie farthest from the granite. (See fig. 699.) In the altered mass the argillaceous beds are hardened, the limestone is saccharoid, the grits quartzose, and in the midst of them is a thin layer of an imperfect granite. It is also an important circumstance that near the point of contact, both the granite and the secondary rocks become metalliferous, and contain nests and small veins of blende, galena, iron, and copper pyrites. The stratified rocks become harder and more crystalline, but the granite, on the contrary, softer and less perfectly crystallized near the junction.*

Fig. 699.



Junction of granite with Jurassic or Oolite strata in the Alps, near Champoleon.

Although the granite is incumbent in the above section (fig. 699.), we cannot assume that it overflowed the strata, for the disturbances of the rocks are so great in this part of the Alps that they seldom retain the position which they must originally have occupied.

A considerable mass of syenite, in the Isle of Skye, is described by Dr. MacCulloch as intersecting limestone and shale, which are of the age of the lias.† The limestone, which at a greater distance from the granite contains shells, exhibits no traces of them near its junction, where it has been converted into a pure crystalline marble.‡

At Predazzo, in the Tyrol, secondary strata, some of which are limestones of the Oolitic period, have been traversed and altered by plutonic rocks, one portion of which is an augitic porphyry, which passes insensibly into granite. The limestone is changed into granular marble, with a band of serpentine at the junction.§

Carboniferous period. — The granite of Dartmoor, in Devonshire, was formerly supposed to be one of the most ancient of the plutonic rocks, but is now ascertained to be posterior in date to the culm-measures of that county, which from their position, and, as containing

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* Elie de Beaumont, sur les Montagnes de l'Oisans, &c. Mém. de la Soc. d'Hist. Nat. de Paris, tom. v.

† Murchison, Geol. Trans. 2d series, vol. ii. part ii. pp. 311—321.

‡ Western Islands, vol. i. p. 330. plate 18., figs. 3, 4.

§ Von Buch, Annales de Chimie, &c.

true coal-plants, are regarded by Professor Sedgwick and Sir R. Murchison as members of the true carboniferous series. This granite, like the syenitic granite of Christiania, has broken through the stratified formations without much changing their strike. Hence, on the north-west side of Dartmoor, the successive members of the culm-measures abut against the granite, and become metamorphic as they approach. These strata are also penetrated by granite veins, and plutonic dikes, called "elvans."* The granite of Cornwall is probably of the same date, and, therefore, as modern as the Carboniferous strata, if not much newer.

Silurian period.—It has long been known that the granite near Christiania, in Norway, is of newer origin than the Silurian strata of that region. Von Buch first announced, in 1813, the discovery of its posteriority in date to limestones containing orthocerata and trilobites. The proofs consist in the penetration of granite veins into the shale and limestone, and the alteration of the strata, for a considerable distance from the point of contact both of these veins and the central mass from which they emanate. (See p. 577.) Von Buch supposed that the plutonic rock alternated with the fossiliferous strata, and that large masses of granite were sometimes incumbent upon the strata; but this idea was erroneous, and arose from the fact that the beds of shale and limestone often dip towards the granite up to the point of contact, appearing as if they would pass under it in mass, as at *a*, fig. 700., and then again on the opposite side of the same mountain, as at *b*, dip away from the same granite. When the junctions, however, are carefully examined, it is found that the plutonic rock intrudes itself in veins, and nowhere covers the fossiliferous strata in large overlying masses, as is so commonly the case with trappean formations.†

Fig. 700.

Now this granite, which is more modern than the Silurian strata of Norway, also sends veins in the same country into an ancient formation of gneiss; and the relations of the plutonic rock and the gneiss, at their junction, are full of interest when we duly consider the wide difference of epoch which must have separated their origin.

The length of this interval of time is attested by the following facts:—The fossiliferous, or Silurian, beds rest unconformably upon the truncated edges of the gneiss, the inclined strata of which had been denuded before the sedimentary beds were superimposed

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* Proceed. Geol. Soc., vol. ii. p. 562.; and Trans. 2d ser. vol. v. p. 686.

† See the Gæa Norvegica and other works of Keilhau, with whom I examined this country.

Fig. 701.

Granite sending veins into Silurian strata and Gneiss, — Christiania, Norway.

(see fig. 701.). The signs of denudation are twofold; first, the surface of the gneiss is seen occasionally, on the removal of the newer beds, containing organic remains, to be worn and smoothed; secondly, pebbles of gneiss have been found in some of these Silurian strata. Between the origin, therefore, of the gneiss and the granite there intervened, first, the period when the strata of gneiss were denuded; secondly, the period of the deposition of the Silurian deposits. Yet the granite produced after this long interval is often so intimately blended with the ancient gneiss, at the point of junction, that it is impossible to draw any other than an arbitrary line of separation between them; and where this is not the case, tortuous veins of granite pass freely through gneiss, ending sometimes in threads, as if the older rock had offered no resistance to their passage. It seems necessary, therefore, to conceive that the gneiss was softened and more or less melted when penetrated by the granite. But had such junctions alone been visible, and had we not learnt, from other sections, how long a period elapsed between the consolidation of the gneiss and the injection of this granite, we might have suspected that the gneiss was scarcely solidified, or had not yet assumed its complete metamorphic character when invaded by the plutonic rock. From this example we may learn how impossible it is to conjecture whether certain granites in Scotland, and other countries, which send veins into gneiss and other metamorphic rocks, are primary, or whether they may not belong to some secondary or tertiary period.

Oldest granites. — It is not half a century since the doctrine was very general that all granitic rocks were *primitive*, that is to say, that they originated before the deposition of the first sedimentary strata, and before the creation of organic beings (see above, p. 9.). But so greatly are our views now changed, that we find it no easy task to point out a single mass of granite demonstrably more ancient than all the known fossiliferous deposits. Could we discover some Lower Cambrian strata resting immediately on granite, there being no alterations at the point of contact, nor any intersecting granitic veins, we might then affirm the plutonic rock to have originated before the oldest known fossiliferous strata. Still it would be presumptuous, as we have already pointed out (p. 456.), to suppose that when a small part only of the globe has been investigated, we are acquainted with the oldest fossiliferous strata in the crust of our planet. Even when these are found, we cannot assume that there never were any antecedent strata containing organic remains, which may have become metamorphic. If we find pebbles of granite in a conglomerate of the Lower Cambrian system, we may then feel assured that the parent granite was formed before the Lower Cambrian formation. But if the incumbent strata be merely Silurian or Upper Cambrian, the fundamental granite, although of high antiquity, may be posterior in date to *known* fossiliferous formations.

Protrusion of solid granite.—In part of Sutherlandshire, near Brora, common granite, composed of felspar, quartz, and mica, is in immediate contact with Oolitic strata, and has clearly been elevated to the surface at a period subsequent to the deposition of those strata.* Professor Sedgwick and Sir R. Murchison conceive that this granite has been upheaved in a solid form; and that in breaking through the submarine deposits, with which it was not perhaps originally in contact, it has fractured them so as to form a breccia along the line of junction. This breccia consists of fragments of shale, sandstone, and limestone, with fossils of the oolite, all united together by a calcareous cement. The secondary strata, at some distance from the granite, are but slightly disturbed, but in proportion to their proximity the amount of dislocation becomes greater.

If we admit that solid hypogene rocks, whether stratified or unstratified, have in such cases been driven upwards so as to pierce through yielding sedimentary deposits, we shall be enabled to account for many geological appearances otherwise inexplicable. Thus, for example, at Weinböhla and Hohnstein, near Meissen, in Saxony, a mass of granite has been observed covering strata of the Cretaceous and Oolitic periods for the space of between 300 and 400 yards square. It appears clearly from a memoir of Dr. B. Cotta on this subject†, that the granite was thrust into its actual position when solid. There are no intersecting veins at the junction,—no alteration as if by heat, but evident signs of rubbing, and a breccia in some places, in which pieces of granite are mingled with broken fragments of the secondary rocks. As the granite overhangs both the lias and chalk, so the lias is in some places bent over strata of the cretaceous era.

Relative age of the granites of Arran.—In this island, the largest in the Firth of Clyde, being twenty miles in length from north to south, the four great classes of rocks, the fossiliferous, volcanic, plutonic, and metamorphic, are all conspicuously displayed within a very small area, and with their peculiar characters strongly contrasted. In the north of the island the granite rises to the height of nearly 3000 feet above the sea, terminating in mountainous peaks. (See section, fig. 702.). On the flanks of the same mountains are chloritic-schists, blue roofing-slate, and other rocks of the metamorphic order (No. 1.), into which the granite (No. 2.) sends veins. This granite, therefore, is newer than the hypogene schists (No. 1.), which it penetrates.

These schists are highly inclined. Upon them rest beds of con-

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* Murchison, Geol. Trans., 2d series, vol. ii. p. 307.

† Geognostische Wanderungen, Leipzig, 1838.

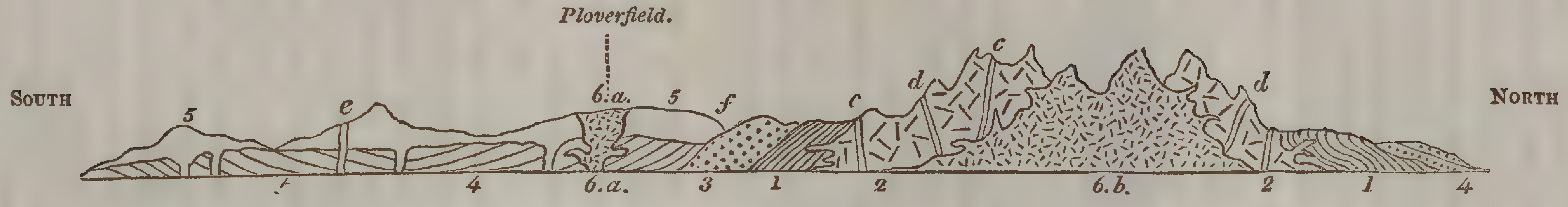
glomerate and sandstone (No. 3.), which are referable to the Old Red formation, to which succeed various shales and limestones (No. 4.) containing the fossils of the Carboniferous period, upon which are other strata of sandstone and conglomerate (upper part of No. 4.), in which no fossils have been met with, which it is conjectured may belong to the New Red sandstone period. All the preceding formations are cut through by the volcanic rocks (No. 5.), which consist of greenstone, basalt, pitchstone, claystone-porphyry, and other varieties. These appear either in the form of dikes, or in dense masses from 50 to 700 feet in thickness, overlying the strata (No. 4.). They sometimes pass into syenite of so crystalline a form, that it may rank as a plutonic formation; and in one region, at Ploverfield, in Glen Cloy, a fine-grained granite (6. *a*) is seen associated with the trap formation, and sending veins into the sandstone or into the upper strata of No. 4. This interesting discovery ot granite in the southern region of Arran, at a point where it is separated from the northern mass of granite by a great thickness of secondary strata and overlying trap, was made by Mr. L. A. Necker of Geneva, during his survey of Arran in 1839. We also learn from later investigations by Prof. A. C. Ramsay, that a similar fine-grained granite (No. 6. *b*) appears in the interior of the northern granitic district, forming the nucleus of it, and sending veins into the older coarse-grained granite (No. 2.). The trap dikes which penetrate the older granite are cut off, according to Mr. Ramsay, at the junction of the fine grained.

It is not improbable that the granite (No. 6. *b*), may be of the same age as that of Ploverfield (No. 6. *a*.), and this again may belong to the same geological epoch as the trap formations (No. 5.). If there be any difference of date, it would seem that the fine-grained granite must be newer than the trappean rocks. But, on the other hand, the coarser granite (No. 2.) may be the oldest rock in Arran, with the exception of the hypogene slates (No. 1.), into which it sends veins.

An objection may perhaps at first be started to this conclusion, derived from the curious and striking fact, the importance of which was first emphatically pointed out by Dr. MacCulloch, that no pebbles of granite occur in the conglomerates of the red sandstone in Arran, although these conglomerates are several hundred feet in thickness, and lie at the foot of lofty granite mountains, which tower above them. As a general rule, all such aggregates of pebbles and sand are mainly composed of the wreck of pre-existing rocks occurring in the immediate vicinity. The total absence therefore of granitic pebbles has justly been a theme of wonder to those geologists who have successively visited Arran, and they have carefully searched there, as I have done myself, to find an exception, but in vain. The rounded masses consist exclusively of quartz, chlorite-schist, and other members of the metamorphic series; nor in the newer conglomerates of No. 4. have any granitic fragments been discovered. Are we then entitled to affirm that the coarse-grained granite (No. 2.), like

Fig. 702.

GENERAL SECTION OF ARRAN FROM NORTH TO SOUTH.



1. Metamorphic or Hypogene schists, the oldest formations in Arran.
2. Coarse-grained granite sending veins into the schists, No. 1.
3. Old Red Sandstone and Conglomerate containing pebbles exclusively derived from the rocks, No. 1., without any intermixture of granitic fragments.
4. Carboniferous strata and red sandstone (New Red?)
5. Trap, overlying and in dikes (*c*, *d*, *e*), passing occasionally into syenites of the Plutonic class.
6\. *a*. Fine-grained granite, associated with the overlying trap, No. 5.
6\. *b*. Similar fine-grained granite, sending veins into the older granite, No. 2., and cutting off the trappean dikes, *c*, *d*.*

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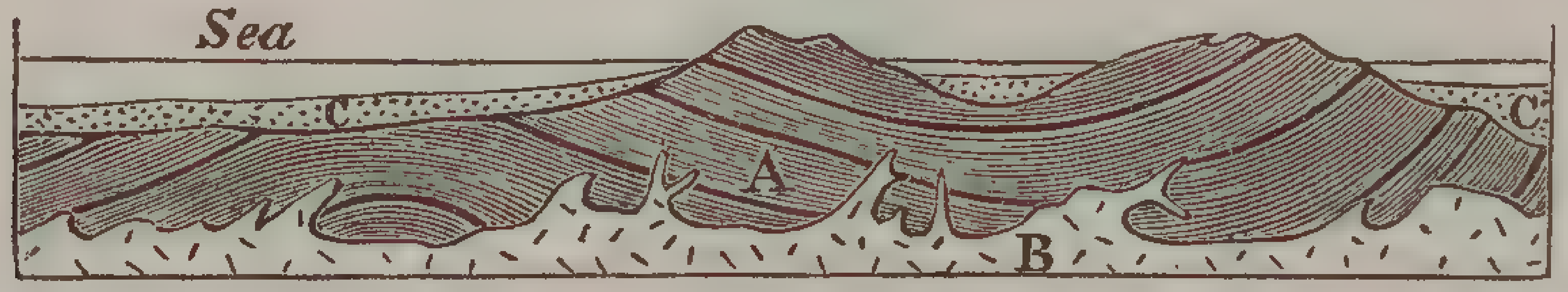
* In the above section I have attempted to represent the new discoveries made by Mr. Necker and Mr. A. C. Ramsay, since 1839, in regard to the more modern plutonic formations, 6. *a*, and 6. *b*. (See p. 460.)

the fine-grained variety (No. 6. *a*), is more modern than all the other rocks of the island? This we cannot assume at present, but we may confidently infer that when the various beds of sandstone and conglomerate were formed, no granite had reached the surface, or had been exposed to denudation in Arran. It is clear that the crystalline schists were ground into sand and shingle when the strata No. 3. were deposited, and at that time the waves had never acted upon the granite, which now sends its veins into the schist. May we then conclude, that the schists suffered denudation before they were invaded by granite? This opinion, although not inadmissible, is by no means fully borne out by the evidence. For at the time when the Old Red Sandstone originated, the metamorphic strata may have formed islands in the sea, as in fig. 703., over which the breakers rolled, or from which torrents and rivers descended, carrying down gravel and sand. The plutonic rock or granite (B) may even then have been previously injected at a certain depth below, and yet may never have been exposed to denudation.

Fig. 703.



As to the time and manner of the subsequent protrusion of the coarse-grained granite (No. 2.), this rock may have been thrust up bodily, in a solid form, during that long series of igneous operations which produced the trappean and plutonic formations (Nos. 5., 6. *a*, and 6. *b*).

We have shown that these eruptions, whatever their date, were posterior to the deposition of all the fossiliferous strata of Arran. We can also prove that subsequently both the granitic and trappean rocks underwent great aqueous denudation, which they probably suffered during their emergence from the sea. The fact is demonstrated by the abrupt truncation of numerous dikes, such as those at *c*, *d*, *e*, which are cut off on the surface of the granite and trap. The overlying trap also ceases very abruptly on approaching the boundary of the great hypogene region, and terminates in a steep escarpment facing towards it as at *f*, fig. 702. When in its original fluid state it could not have come thus suddenly to an end, but must have filled up the hollow now separating it from the hypogene rocks, had such a hollow then existed. This necessity of supposing that both the trap and the conglomerate once extended farther, and that veins such as *c*, *d*, fig. 702., were once prolonged farther upwards, prepares us to believe that the whole of the northern granite may at one time have been covered by newer formations, under the pressure of which, before its protrusion, it assumed its highly crystalline texture.

The theory of the protrusion in a solid form of the northern nucleus of granite is confirmed by the manner in which the hypogene slates (No. 1.) and the beds of conglomerate (No. 3.) dip away from it on all sides. In some places indeed the slates are inclined towards the granite, but this exception might have been looked for, because these hypogene strata have undergone disturbances at more than one geological epoch, and may at some points, perhaps, have their original order of position inverted. The high inclination, therefore, and the quâquâversal dip of the beds around the borders of the granitic boss, and the comparative horizontality of the fossiliferous strata in the southern part of the island, are facts which all accord with the hypothesis of a great amount of movement at that point where the granite is supposed to have been thrust up bodily, and where we may conceive it to have been distended laterally by the repeated injection of fresh supplies of melted materials.*

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* For the geology of Arran consult the works of Drs. Hutton and MacCulloch, the Memoirs of Messrs. Von Dechen and Oeynhausen, that of Professor Sedgwick and Sir R. Murchison (Geol. Trans. 2d series) Mr. L. A. Necker's Memoir, read to the Royal Soc. of Edin. 20th April, 1840, and Mr. Ramsay's Geol. of Arran, 1841. I examined myself a large part of Arran in 1836.

CHAPTER XXXV.

METAMORPHIC ROCKS.

General character of metamorphic rocks — Gneiss — Hornblende-schist — Mica-schist — Clay-slate — Quartzite — Chlorite-schist — Metamorphic limestone — Alphabetical list and explanation of the more abundant rocks of this family —Origin of the metamorphic strata — Their stratification — Fossiliferous strata near intrusive masses of granite converted into rocks identical with different members of the metamorphic series — Arguments hence derived as to the nature of plutonic action — Time may enable this action to pervade denser masses — From what kinds of sedimentary rock each variety of the metamorphic class may be derived — Certain objections to the metamorphic theory considered — Partial conversion of Eocene slate into gneiss.

WE have now considered three distinct classes of rocks: first, the aqueous, or fossiliferous; secondly, the volcanic; and, thirdly, the plutonic, or granitic; and we have now, lastly, to examine those crystalline (or hypogene) strata to which the name of *metamorphic* has been assigned. The last-mentioned term expresses, as before explained, a theoretical opinion that such strata, after having been deposited from water, acquired, by the influence of heat and other causes, a highly crystalline texture. They who still question this opinion may call the rocks under consideration the stratified hypogene, or schistose hypogene formations.

These rocks, when in their most characteristic or normal state, are wholly devoid of organic remains, and contain no distinct fragments of other rocks, whether rounded or angular. They sometimes break out in the central parts of narrow mountain chains, but in other cases extend over areas of vast dimensions, occupying, for example, nearly the whole of Norway and Sweden, where, as in Brazil, they appear alike in the lower and higher grounds. In Great Britain, those members of the series which approach most nearly to granite in their composition, as gneiss, mica-schist, and hornblende-schist, are confined to the country north of the rivers Forth and Clyde.

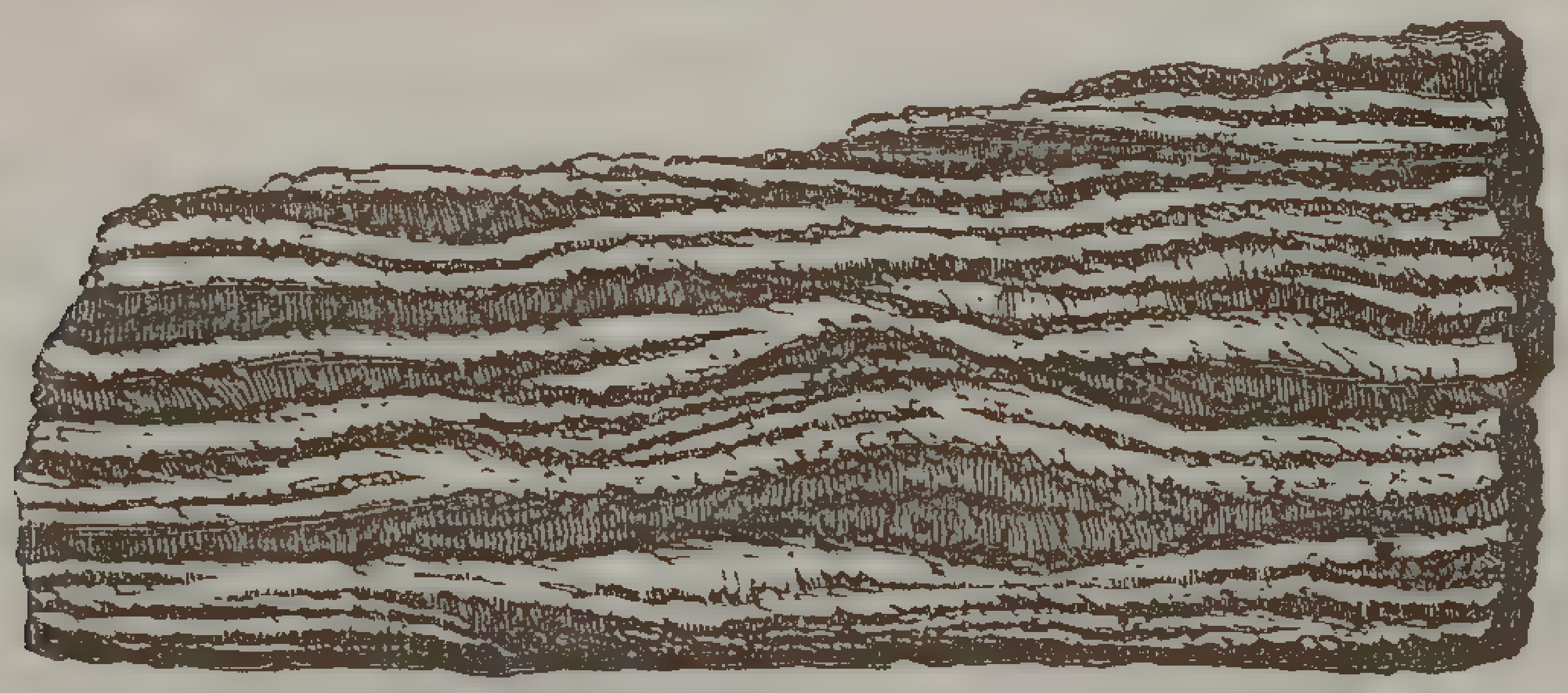
However crystalline these rocks may become in certain regions, they never, like granite or trap, send veins into contiguous formations, whether into an older schist or granite or into a set of newer fossiliferous strata.

Many attempts have been made to trace a general order of succession or superposition in the members of this family; clay-slate, for example, having been often supposed to hold invariably a higher geological position than mica-schist, and mica-schist always to overlie gneiss. But although such an order may prevail throughout limited districts, it is by no means universal. To this subject, however, I shall again revert, in the 37th chapter, when the chronological relations of the metamorphic rocks are pointed out.

The following may be enumerated as the principal members of the metamorphic class:—gneiss, mica-schist, hornblende-schist, clay-slate, chlorite-schist, hypogene or metamorphic limestone, and certain kinds of quartz-rock or quartzite.

Gneiss. — The first of these, gneiss, may be called stratified, or, by those who object to that term, foliated, granite, being formed of the same materials as granite, namely, felspar, quartz, and mica. In the specimen here figured, the white layers consist almost exclusively of granular felspar, with here and there a speck of mica and grain of quartz. The dark layers are composed of grey quartz and black mica, with occasionally a grain of felspar intermixed. The rock splits most easily in the plane of these darker layers, and the surface thus exposed is almost entirely covered with shining spangles of mica. The accompanying quartz, however, greatly predominates in quantity, but the most ready cleavage is determined by the abundance of mica in certain parts of the dark layer.

Fig. 704.



Fragment of gneiss, natural size: section made at right angles to the planes of foliation.

Instead of consisting of these thin laminæ, gneiss is sometimes simply divided into thick beds, in which the mica has only a slight degree of parallelism to the planes of stratification.

The term "gneiss," however, in geology is commonly used in a wider sense, to designate a formation in which the above-mentioned rock prevails, but with which any one of the other metamorphic rocks, and more especially hornblende-schist, may alternate. These other members of the metamorphic series are, in this case, considered as subordinate to the true gneiss.

The different varieties of rock allied to gneiss, into which felspar enters as an essential ingredient, will be understood by referring to what was said of granite. Thus, for example, hornblende may be superadded to mica, quartz, and felspar, forming a syenitic gneiss; or talc may be substituted for mica, constituting talcose gneiss, a rock composed of felspar, quartz, and talc, in distinct crystals or grains (stratified protogine of the French).

Hornblende-schist is usually black, and composed principally of hornblende, with a variable quantity of felspar, and sometimes grains of quartz. When the hornblende and felspar are nearly in equal quantities, and the rock is not slaty, it corresponds in character with the greenstones of the trap family, and has been called "primitive greenstone." It may be termed hornblende rock. Some of these hornblendic masses may really have been volcanic rocks, which have since assumed a more crystalline or metamorphic texture.

Mica-schist, or *Micaceous schist*, is, next to gneiss, one of the most abundant rocks of the metamorphic series. It is slaty, essentially composed of mica and quartz, the mica sometimes appearing to constitute the whole mass. Beds of pure quartz also occur in this formation. In some districts, garnets in regular twelve-sided crystals form an integrant part of mica-schist. This rock passes by insensible gradations into clay-slate.

Clay-slate, or *Argillaceous schist.*—This rock sometimes resembles an indurated clay or shale. It is for the most part extremely fissile, often affording good roofing-slate. Occasionally it derives a shining and silky lustre from the minute particles of mica or talc which it contains. It varies from greenish or bluish-grey to a lead colour; and it may be said of this, more than of any other schist, that it is common to the metamorphic and fossiliferous series, for some clay-slates taken from each division would not be distinguishable by mineral characters alone.

Quartzite, or *Quartz rock*, is an aggregate of grains of quartz which are either in minute crystals, or in many cases slightly rounded, occurring in regular strata, associated with gneiss or other metamorphic rocks. Compact quartz, like that so frequently found in veins, is also found together with granular quartzite. Both of these alternate with gneiss or mica-schist, or pass into those rocks by the addition of mica, or of felspar and mica.

Chlorite-schist is a green slaty rock, in which chlorite is abundant in foliated plates, usually blended with minute grains of quartz, or sometimes with felspar or mica; often associated with, and graduating into, gneiss and clay-slate.

Crystalline or *Metamorphic limestone.*—This hypogene rock, called by the earlier geologists *primary limestone*, is sometimes a white crystalline granular marble, which when in thick beds can be used in sculpture; but more frequently it occurs in thin beds, forming a foliated schist much resembling in colour and appearance certain varieties of gneiss and mica-schist. When it alternates with these rocks, it often contains some crystals of mica, and occasionally quartz, felspar, hornblende, talc, chlorite, garnet, and other minerals. It enters sparingly into the structure of the hypogene districts of Norway, Sweden, and Scotland, but is largely developed in the Alps.

Before offering any farther observations on the probable origin of the metamorphic rocks, I subjoin, in the form of a glossary, a brief explanation of some of the principal varieties and their synonyms.

Explanation of the Names, Synonyms, and Mineral Composition of the more abundant Metamorphic Rocks.

ACTINOLITE-SCHIST. A slaty foliated rock, composed chiefly of actinolite, (an emerald-green mineral, allied to hornblende,) with some admixture of garnet, mica, and quartz.

AMPELITE. Aluminous slate (Brongniart); occurs both in the metamorphic and fossiliferous series.

AMPHIBOLITE, Hornblende rock, which see.

ARGILLACEOUS-SCHIST, or CLAY-SLATE. *See* p. 596.

ARKOSE. Name given by Brongniart to a compound of the same materials as granite, which it often resembles closely. It is found at the junction of granite with formations of different ages, and consists of crystals of felspar, quartz, and sometimes mica, which, after separation from their original matrix by disintegration, have been reunited by a siliceous or quartzose cement. It is often penetrated by quartz veins.

CHIASTOLITE-SLATE scarcely differs from clay-slate, but includes numerous crystals of Chiastolite: in considerable thickness in Cumberland. Chiastolite occurs in long slender rhomboidal crystals. For composition, see Table, p. 479.

CHLORITE-SCHIST. A green slaty rock, in which chlorite, a green scaly mineral, is abundant. *See* p. 596.

CLAY-SLATE or ARGILLACEOUS-SCHIST. *See* p. 596.

EURITE has been already mentioned as a plutonic rock (p. 569.), but occurs also with precisely the same composition in beds subordinate to gneiss or mica-slate.

GNEISS. A stratified or foliated rock; has the same composition as granite. *See* p. 595.

HORNBLENDE ROCK, or AMPHIBOLITE. *See* above, p. 477. A member both of the volcanic and metamorphic series. Agrees in composition with hornblende-schist, but is not fissile.

HORNBLENDE-SCHIST, or SLATE. Composed of hornblende and felspar. *See* p. 595.

HORNBLENDIC or SYENITIC GNEISS. Composed of felspar, quartz, and hornblende.

HYPOGENE LIMESTONE. *See* p. 596.

MARBLE. *See* pp. 12. & 596.

MICA-SCHIST, or MICACEOUS-SCHIST. A slaty rock, composed of mica and quartz, in variable proportions. *See* p. 596.

MICA-SLATE. *See* MICA-SCHIST, p. 596.

PHYLLADE. D'Aubuisson's term for clay-slate, from φυλλας, a heap of leaves.

PRIMARY LIMESTONE. *See* HYPOGENE LIMESTONE, p. 596.

PROTOGINE. *See* TALCOSE-GNEISS, p. 595.; when unstratified it is Talcose-granite.

QUARTZ ROCK, or QUARTZITE. A stratified rock; an aggregate of grains of quartz. *See* p. 596.

SERPENTINE has already been described (p. 478.) because it occurs in both divisions of the hypogene series, as a stratified or unstratified rock.

TALCOSE-GNEISS. Same composition as talcose-granite or protogine, but stratified or foliated. *See* p. 595.

TALCOSE-SCHIST consists chiefly of talc, or of talc and quartz, or of talc and felspar, and has a texture something like that of clay-slate.

Origin of the Metamorphic Strata.

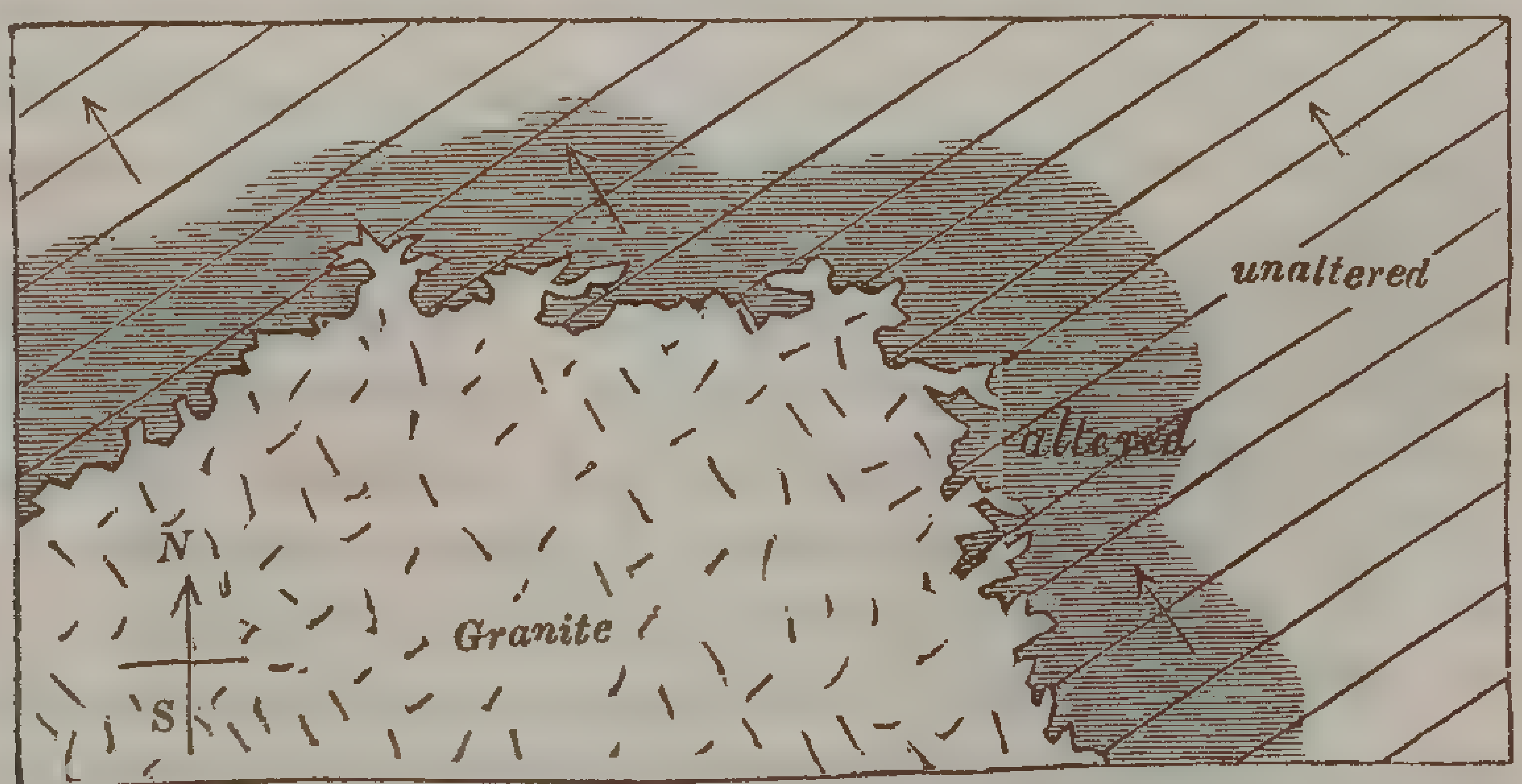
Having said thus much of the mineral composition of the metamorphic rocks, I may combine what remains to be said of their structure and history with an account of the opinions entertained of their probable origin. At the same time, it may be well to forewarn the reader that we are here entering upon ground of controversy, and soon reach the limits where positive induction ends, and beyond which we can only indulge in speculations. It was once a favourite doctrine, and is still maintained by many, that these rocks owe their crystalline texture, their want of all signs of a mechanical origin, or of fossil contents, to a peculiar and nascent condition of the planet at the period of their formation. The arguments in refutation of this hypothesis will be more fully considered when I show, in the last chapter of this volume, to how many different ages the metamorphic formations are referable, and how gneiss, mica-schist, clay-slate, and hypogene limestone (that of Carrara for example) have been formed, not only since the first introduction of organic beings into this planet, but even long after many distinct races of plants and animals had passed away in succession.

The doctrine respecting the crystalline strata, implied in the name metamorphic, may properly be treated of in this place; and we must first inquire whether these rocks are really entitled to be called stratified in the strict sense of having been originally deposited as sediment from water. The general adoption by geologists of the term stratified, as applied to these rocks, sufficiently attests their division into beds very analogous, at least in form, to ordinary fossiliferous strata. This resemblance is by no means confined to the existence in both occasionally of a laminated structure, but extends to every kind of arrangement which is compatible with the absence of fossils, and of sand, pebbles, ripple-mark, and other characters which the metamorphic theory supposes to have been obliterated by plutonic action. Thus, for example, we behold alike in the crystalline and fossiliferous formations an alternation of beds varying greatly in composition, colour, and thickness. We observe, for instance, gneiss alternating with layers of black hornblende-schist, or of green chlorite-schist, or with granular quartz, or limestone; and the interchange of these different strata may be repeated for an indefinite number of times. In the like manner, mica-schist alternates with chlorite-schist, and with beds of pure quartz or of granular limestone.

We have already seen that, near the immediate contact of granitic veins and volcanic dikes, very extraordinary alterations in rocks have taken place, more especially in the neighbourhood of granite. It will be useful here to add other illustrations, showing that a texture undistinguishable from that which characterizes the more crystalline metamorphic formations has actually been superinduced in strata once fossiliferous.

In the southern extremity of Norway there is a large district, on the west side of the fiord of Christiania, in which granite or syenite protrudes in mountain masses through fossiliferous strata, and usually sends veins into them at the point of contact. The stratified rocks, replete with shells and zoophytes, consist chiefly of shale, limestone, and some sandstone, and all these are invariably altered near the granite for a distance of from 50 to 400 yards. The aluminous shales are hardened and have become flinty. Sometimes they resemble jasper. Ribboned jasper is produced by the hardening of alternate layers of green and chocolate-coloured schist, each stripe faithfully representing the original lines of stratification. Nearer the granite the schist often contains crystals of hornblende, which are even met with in some places for a distance of several hundred yards from the junction; and this black hornblende is so abundant that eminent geologists, when passing through the country, have confounded it with the ancient hornblende-schist, subordinate to the great gneiss formation of Norway. Frequently, between the granite and the hornblende slate, above-mentioned, grains of mica and crystalline felspar appear in the schist, so that rocks resembling gneiss and mica-schist are produced. Fossils can rarely be detected in these schists, and they are more completely effaced in proportion to the more crystalline texture of the beds, and their vicinity to the granite. In some places the siliceous matter of the schist becomes a granular quartz; and when hornblende and mica are added, the altered rock loses its stratification, and passes into a kind of granite. The limestone, which at points remote from the granite is of an earthy texture and blue colour, and often abounds in corals, becomes a white granular marble near the granite, sometimes siliceous, the granular structure extending occasionally upwards of 400 yards from the junction; the corals being for the most part obliterated, though sometimes preserved, even in the white marble. Both the altered limestone and hardened slate contain garnets in many places, also ores of iron, lead, and copper, with some silver. These alterations occur equally, whether the granite invades the strata in a line parallel to the general strike of the fossiliferous beds, or in a line at

Fig. 705.



Altered zone of fossiliferous slate and limestone near granite. Christiania.
The arrows indicate the dip, and the straight lines the strike, of the beds.

right angles to their strike, as will be seen by the accompanying ground plan.*

The indurated and ribboned schists above mentioned bear a strong resemblance to certain shales of the coal found at Russell's Hall, near Dudley, where coal-mines have been on fire for ages. Beds of shale of considerable thickness, lying over the burning coal, have been baked and hardened so as to acquire a flinty fracture, the layers being alternately green and brick-coloured.

The granite of Cornwall, in like manner, sends forth veins into a coarse argillaceous-schist, provincially termed killas. This killas is converted into hornblende-schist near the contact with the veins. These appearances are well seen at the junction of the granite and killas, in St. Michael's Mount, a small island nearly 300 feet high, situated in the bay, at a distance of about three miles from Penzance.

The granite of Dartmoor, in Devonshire, says Sir H. De la Beche, has intruded itself into the slate and slaty sandstone called greywacké, twisting and contorting the strata, and sending veins into them. Hence some of the slate rocks have become "micaceous; others more indurated, and with the characters of mica-slate and gneiss; while others again appear converted into a hard-zoned rock strongly impregnated with felspar." †

We learn from the investigations of M. Dufrénoy, that in the eastern Pyrenees there are mountain masses of granite posterior in date to the formations called lias and chalk of that district, and that these fossiliferous rocks are greatly altered in texture, and often charged with iron-ore, in the neighbourhood of the granite. Thus in the environs of St. Martin, near St. Paul de Fénouillet, the chalky limestone becomes more crystalline and saccharoid as it approaches the granite, and loses all trace of the fossils which it previously contained in abundance. At some points, also, it becomes dolomitic, and filled with small veins of carbonate of iron, and spots of red iron-ore. At Rancié the lias nearest the granite is not only filled with iron-ore, but charged with pyrites, tremolite, garnet, and a new mineral somewhat allied to felspar, called, from the place in the Pyrenees where it occurs, "couzeranite."

Now the alterations above described as superinduced in rocks by volcanic dikes and granite veins prove incontestably that powers exist in nature capable of transforming fossiliferous into crystalline strata—powers capable of generating in them a new mineral character, similar to, nay, often absolutely identical with that of gneiss, mica-schist, and other stratified members of the hypogene series. The precise nature of these altering causes, which may provisionally be termed plutonic, is in a great degree obscure and doubtful; but their reality is no less clear, and we must suppose the influence of heat to be in some way connected with the transmutation, if, for reasons before explained, we concede the igneous origin of granite.

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* Keilhau, Gæa Norvegica, pp. 61—63.

† Geol. Manual, p. 479.

The experiments of Gregory Watt, in fusing rocks in the laboratory, and allowing them to consolidate by slow cooling, prove distinctly that a rock need not be perfectly melted in order that a re-arrangement of its component particles should take place, and a partial crystallization ensue.* We may easily suppose, therefore, that all traces of shells and other organic remains may be destroyed; and that new chemical combinations may arise, without the mass being so fused as that the lines of stratification should be wholly obliterated.

We must not, however, imagine that heat alone, such as may be applied to a stone in the open air, can constitute all that is comprised in plutonic action. We know that volcanos in eruption not only emit fluid lava, but give off steam and other heated gases, which rush out in enormous volume, for days, weeks, or years continuously, and are even disengaged from lava during its consolidation. When the materials of granite, therefore, came in contact with the fossiliferous stratum in the bowels of the earth under great pressure, the contained gases might be unable to escape; yet when brought into contact with rocks, they might pass through their pores with greater facility than water is known to do (p. 35.). These aeriform fluids, such as sulphuretted hydrogen, muriatic acid, and carbonic acid, issue in many places from rents in rocks, which they have discoloured and corroded, softening some and hardening others. If the rocks are charged with water, they would pass through more readily; for, according to the experiments of Henry, water, under an hydrostatic pressure of 96 feet, will absorb three times as much carbonic acid gas as it can under the ordinary pressure of the atmosphere. Although this increased power of absorption would be diminished in consequence of the higher temperature found to exist as we descend in the earth, yet Professor Bischoff has shown that the heat by no means augments in such a proportion as to counteract the effect of augmented pressure.† There are other gases, as well as the carbonic acid, which water absorbs, and more rapidly in proportion to the amount of pressure. Now even the most compact rocks may be regarded, before they have been exposed to the air and dried, in the light of sponges filled with water; and it is conceivable that heated gases brought into contact with them, at great depths, may be absorbed readily, and transfused through their pores. Although the gaseous matter first absorbed would soon be condensed, and part with its heat, yet the continual arrival of fresh supplies from below might, in the course of ages, cause the temperature of the water, and with it that of the containing rock, to be materially raised.

M. Fournet, in his description of the metalliferous gneiss near Clermont, in Auvergne, states that all the minute fissures of the rock are quite saturated with free carbonic acid gas; which gas rises plentifully from the soil there and in many parts of the surrounding

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* Phil. Trans., 1804.

† Poggendorf's Annalen, No. xvi., 2d series, vol. iii.

country. The various elements of the gneiss, with the exception of the quartz, are all softened; and new combinations of the acid with lime, iron, and manganese are continually in progress.*

Another illustration of the power of subterranean gases is afforded by the stufas of St. Calogero, situated in the largest of the Lipari Islands. Here, according to the description published by Hoffmann, horizontal strata of tuff, extending for 4 miles along the coast, and forming cliffs more than 200 feet high, have been discoloured in various places, and strangely altered by the "all-penetrating vapours." Dark clays have become yellow, or often snow-white; or have assumed a chequered or brecciated appearance, being crossed with ferruginous red stripes. In some places the fumeroles have been found by analysis to consist partly of sublimations of oxide of iron; but it also appears that veins of chalcedony and opal, and others of fibrous gypsum, have resulted from these volcanic exhalations.†

The reader may also refer to M. Virlet's account of the corrosion of hard, flinty, and jaspideous rocks near Corinth by the prolonged agency of subterranean gases‡; and to Dr. Daubeny's description of the decomposition of trachytic rocks in the Solfatara, near Naples, by sulphuretted hydrogen and muriatic acid gases.§

Although in all these instances we can only study the phenomena as exhibited at the surface, it is clear that the gaseous fluids must have made their way through the whole thickness of porous or fissured rocks, which intervene between the subterranean reservoirs of gas and the external air. The extent, therefore, of the earth's crust which the vapours have permeated and are now permeating may be thousands of fathoms in thickness, and their heating and modifying influence may be spread throughout the whole of this solid mass.

We learn from Professor Bischoff that the steam of a hot spring at Aix-la-Chapelle, although its temperature is only from 133° to 167° F., has converted the surface of some blocks of black marble into a doughy mass. He conceives, therefore, that steam in the bowels of the earth having a temperature equal or even greater than the melting point of lava, and having an elasticity of which even Papin's digester can give but a faint idea, may convert rocks into liquid matter.‖

The above observations are calculated to meet some of the objections which have been urged against the metamorphic theory on the ground of the small power of rocks to conduct heat; for it is well known that rocks, when dry and in the air, differ remarkably from metals in this respect. It has been asked how the changes

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* See Principles, *Index*, "Carbonated Springs," &c.

† Hoffmann's Liparischen Inseln, p. 38. Leipzig, 1832.

‡ See Princ. of Geol.; and Bulletin de la Soc. Géol. de France, tom. ii. p. 230.

§ See Princ. of Geol.; and Daubeny's Volcanos, p. 167.

‖ Jam. Ed. New Phil. Journ., No. 51. p. 43.

which extend merely for a few feet from the contact of a dike could have penetrated through mountain masses of crystalline strata several miles in thickness. Now it has been stated that the plutonic influence of the syenite of Norway has sometimes altered fossiliferous strata for a distance of a quarter of a mile, both in the direction of their dip and of their strike. (See fig. 705. p. 599.) This is undoubtedly an extreme case; but is it not far more philosophical to suppose that this influence may, under favourable circumstances, affect denser masses, than to invent an entirely new cause to account for effects merely differing in quantity, and not in kind? The metamorphic theory does not require us to affirm that some contiguous mass of granite has been the altering power; but merely that an action, existing in the interior of the earth at an unknown depth, whether thermal, hydro-thermal, electrical, or other, analogous to that exerted near intruding masses of granite, has, in the course of vast and indefinite periods, and when rising perhaps from a large heated surface, reduced strata thousands of yards thick to a state of semifusion, so that on cooling they have become crystalline, like gneiss. Granite may have been another result of the same action in a higher state of intensity, by which a thorough fusion has been produced; and in this manner the passage from granite into gneiss may be explained.

In considering, then, the various data already enumerated, the forms of stratification and lamination in metamorphic rocks, their passage on the one hand into the fossiliferous, and on the other into the plutonic formations, and the conversions which can be ascertained to have occurred in the vicinity of granite, we may conclude that gneiss and mica-schist may be nothing more than altered micaceous and argillaceous sandstones, that granular quartz may have been derived from siliceous sandstone, and compact quartz from the same materials. Clay-slate may be altered shale, and granular marble may have originated in the form of ordinary limestone, replete with shells and corals, which have since been obliterated; and, lastly, calcareous sands and marls may have been changed into impure crystalline limestones.

"Hornblende-schist," says Dr. MacCulloch, "may at first have been mere clay; for clay or shale is found altered by trap into Lydian stone, a substance differing from hornblende-schist almost solely in compactness and uniformity of texture."* "In Shetland," remarks the same author, "argillaceous-schist (or clay-slate), when in contact with granite, is sometimes converted into hornblende-schist, the schist becoming first siliceous, and ultimately, at the contact, hornblende-schist."†

The anthracite and plumbago associated with hypogene rocks may have been coal; for not only is coal converted into anthracite in the vicinity of some trap dikes, but we have seen that a like change has taken place generally even far from the contact of

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* Syst. of Geol. vol. i. p. 210.

† Ibid., p. 211.

igneous rocks, in the disturbed region of the Appalachians.* At Worcester, in the state of Massachusetts, 45 miles due west of Boston, a bed of plumbago and impure anthracite occurs, interstratified with mica-schist. It is about 2 feet in thickness, and has been made use of both as fuel, and in the manufacture of lead pencils. At the distance of 30 miles from the plumbago, there occurs, on the borders of Rhode Island, an impure anthracite in slates containing impressions of coal-plants of the genera *Pecopteris*, *Neuropteris*, *Calamites*, &c. This anthracite is intermediate in character between that of Pennsylvania and the plumbago of Worcester, in which last the gaseous or volatile matter (hydrogen, oxygen, and nitrogen) is to the carbon only in the proportion of 3 per cent. After traversing the country in various directions, I came to the conclusion that the carboniferous shales or slates with anthracite and plants, which in Rhode Island often pass into mica-schist, have at Worcester assumed a perfectly crystalline and metamorphic texture; the anthracite having been nearly transmuted into that state of pure carbon which is called plumbago or graphite.†

It has been remarked by M. Delesse that the minerals developed in hypogene limestone vary according to the degree of metamorphism which the rock has undergone. Thus, for example, where the structure is but slightly crystalline, talc, chlorite, serpentine, andalusite, and kyanite are commonly present; where it is more highly crystallized, garnet, hornblende, Wollastonite, dipyre, Couzeranite, and some others appear; and, lastly, where the crystallization is complete, there are found, in addition to many of the above minerals, felspar, especially those kinds which are richest in alkali, together with mica. The same author observes that, as calcareous deposits usually contain some aluminous clay, so we may naturally expect to meet with silicates of alumina in crystalline limestone; such silicates, accordingly, are frequent, and occasionally even pure alumina crystallized in the form of corundum.‡

Mr. Dana has suggested that the phosphoric acid of phosphate of lime, and the fluor of fluor-spar, so often met with in crystalline limestones, may have been derived from the remains of mollusca and other animals; also that graphite (which is pure carbon in a crystalline form, with or without admixture of alumina, lime, or iron) may have been derived from vegetable remains imbedded in the orignal matrix.

The total absence of any trace of fossils has inclined many geologists to attribute the origin of the crystalline strata to a period antecedent to the existence of organic beings. Admitting, they say, the obliteration, in some cases, of fossils by plutonic action, we might still expect that traces of them would oftener occur in certain ancient systems of slate, in which, as in Cumberland, some conglomerates

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* See above, pp. 392, 398.

† See Lyell, Quart. Geol. Journ., vol. i. p. 199.

‡ Delesse, Bulletin Soc. Géol. France, 2e série, tom. 9. p. 126. 1851.

occur. But in urging this argument, it seems to have been forgotten that there are stratified formations of enormous thickness, and of various ages, and some of them very modern, all formed after the earth had become the abode of living creatures, which are, nevertheless, in certain districts, entirely destitute of all vestiges of organic bodies. In some, the traces of fossils may have been effaced by water and acids, at many successive periods; and it is clear, that, the older the stratum, the greater is the chance of its being nonfossiliferous, even if it has escaped all metamorphic action.

It has been also objected to the metamorphic theory, that the chemical composition of the secondary strata differs essentially from that of the crystalline schists, into which they are supposed to be convertible.* The "primary" schists, it is said, usually contain a considerable proportion of potash or of soda, which the secondary clays, shales, and slates do not, these last being the result of the decomposition of felspathic rocks, from which the alkaline matter has been abstracted during the process of decomposition. But this reasoning proceeds on insufficient and apparently mistaken data; for a large portion of what is usually called clay, marl, shale, and slate does actually contain a certain, and often a considerable, proportion of alkali; so that it is difficult, in many countries, to obtain clay or shale sufficiently free from alkaline ingredients to allow of their being burnt into bricks or used for pottery.

Thus the argillaceous shales and slates of the Old Red sandstone, in Forfarshire and other parts of Scotland, are so much charged with alkali, derived from triturated felspar, that, instead of hardening when exposed to fire, they sometimes melt into a glass. They contain no lime, but appear to consist of extremely minute grains of the various ingredients of granite, which are distinctly visible in the coarser-grained varieties, and in almost all the interposed sandstones. These laminated clays and shales might certainly, if crystallized, resemble in composition many of the primary strata.

There is also potash in fossil vegetable remains, and soda in the salts by which strata are sometimes so largely impregnated, as in Patagonia. But recent analysis may be said to have settled the point at issue, by demonstrating that the carboniferous strata in England †, the Upper and Lower Silurian in East Canada ‡, and the clay-slates (of Cambrian date ?) in Norway §, all contain as much alkali as is generally present in metamorphic rocks.

Another objection has been derived from the alternation of highly crystalline strata with others having a less crystalline texture. The heat, it is said, in its ascent from below, must have traversed the less altered schists before it reached a higher and more crystalline bed. In answer to this, it may be observed, that if a number of strata differing greatly in composition from each other be subjected

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* Dr. Boase, Primary Geology, p. 319.

† H. Taylor, Edin. New. Phil. Journ. vol. l. 1851, p. 140.

‡ Hunt, Phil. Mag. 4 ser. vol. vii. p. 237.

§ Kyersly, Norsk, Mag. for Naturvidenp. vol. viii. p. 172.

to equal quantities of heat, there is every probability that some will be more fusible than others. Some, for example, will contain soda, potash, lime, or some other ingredient capable of acting as a flux; while others may be destitute of the same elements, and so refractory as to be very slightly affected by a degree of heat capable of reducing others to semi-fusion. Nor should it be forgotten that, as a general rule, the less crystalline rocks do really occur in the upper, and the more crystalline in the lower part of each metamorphic series.

Moreover, metamorphism must often begin to exert its force long after the strata have assumed a vertical position, and it may then act locally or within limited areas, and will be as likely to affect the newer as the older beds. As an illustration of such partial conversion into gneiss of portions of a highly inclined set of beds, I may cite Sir R. Murchison's memoir on the structure of the Alps. Slates provincially termed "flysch" (see above p. 231.), overlying the nummulite limestone of Eocene date, and comprising some arenaceous and some calcareous layers, are seen to alternate several times with bands of granitoid rock, answering in character to gneiss.* In this case heat, or vapour, or water at an intensely high temperature may have traversed the more permeable beds, and altered them so far as to admit of an internal movement and re-arrangement of the molecules, while the adjoining strata did not give passage to the same heat, or if so, remained unchanged because they were composed of less fusible materials. Whatever hypothesis we adopt, the phenomena establish beyond a doubt the possibility of the development of the metamorphic structure in a tertiary deposit in planes parallel to those of stratification.

Whether such parallelism be the rule or the exception in gneiss, mica-schist, and other formations of the same family, is a question which I shall discuss at length in the next chapter.

* Geol. Quart. Journ. vol. v. p. 211. 1848.

CHAPTER XXXVI.

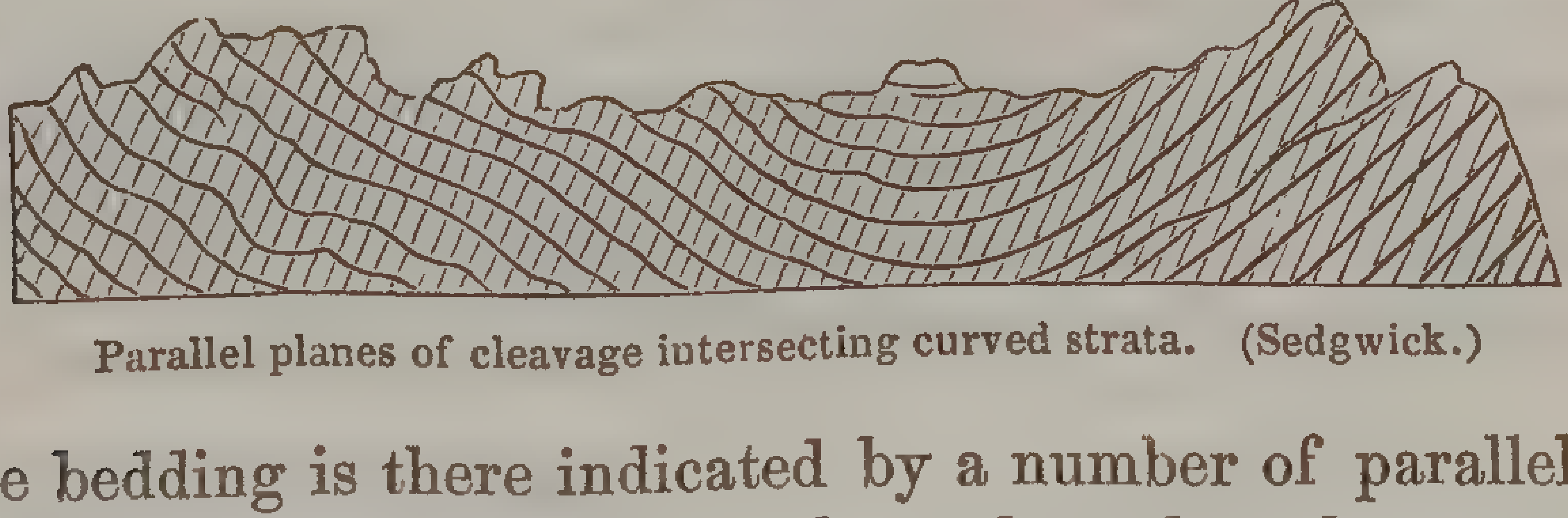
Origin of the metamorphic rocks, *continued* — Definition of joints, slaty cleavage and foliation—Supposed causes of these structures—Mechanical theory of cleavage—Condensation and elongation of slate rocks by lateral pressure—Supposed combination of crystalline and mechanical forces — Lamination of some volcanic rocks due to motion — Whether the foliation of the crystalline schists be usually parallel with the original planes of stratification—Examples in Norway and Scotland—Foliation in homogeneous rocks may coincide with planes of cleavage, and in uncleaved rocks with those of stratification — Causes of irregularity in the planes of foliation.

We have already seen that crystalline forces of great intensity have frequently acted upon sedimentary and fossiliferous strata long subsequently to their consolidation, and we may next inquire whether the component minerals of the altered rocks usually arrange themselves in planes parallel to the original planes of stratification, or whether, after crystallization, they more commonly take up a different position.

In order to estimate fairly the merits of this question, we must first define what is meant by the terms cleavage and foliation. There are four distinct forms of structure exhibited in rocks, namely, stratification, joints, slaty cleavage, and foliation; and all these must have different names, even though there be cases where it is impossible, after carefully studying the appearances, to decide upon the class to which they belong.

Professor Sedgwick, whose essay "On the Structure of large Mineral Masses" first cleared the way towards a better understanding of this difficult subject, observes, that joints are distinguishable from lines of slaty cleavage in this, that the rock intervening between two joints has no tendency to cleave in a direction parallel to the planes of the joints, whereas a rock is capable of indefinite subdivision in the direction of its slaty cleavage. In some cases where the strata are curved, the planes of cleavage are still perfectly parallel. This has been observed in the slate rocks of part of Wales (see fig. 706.), which consist of a hard greenish slate.

Fig. 706.



Parallel planes of cleavage intersecting curved strata. (Sedgwick.)

The true bedding is there indicated by a number of parallel stripes, some of a lighter and some of a darker colour than the general mass.

Such stripes are found to be parallel to the true planes of stratification, wherever these are manifested by ripple-mark, or by beds containing peculiar organic remains. Some of the contorted strata are of a coarse mechanical structure, alternating with fine-grained crystalline chloritic slates, in which case the same slaty cleavage extends through the coarser and finer beds, though it is brought out in greater perfection in proportion as the materials of the rock are fine and homogeneous. It is only when these are very coarse that the cleavage planes entirely vanish. These planes are usually inclined at a very considerable angle to the planes of the strata. In the Welsh hills, for example, the average angle is as much as from 30° to 40°. Sometimes the cleavage planes dip towards the same point of the compass as those of stratification, but more frequently to opposite points. It may be stated as a general rule, that when beds of coarser materials alternate with those composed of finer particles, the slaty cleavage is either entirely confined to the fine-grained rock, or is very imperfectly exhibited in that of coarser texture. This rule holds, whether the cleavage is parallel to the planes of stratification or not.*

In regard to joints, they are natural fissures which often traverse rocks in straight and well-determined lines. They afford to the quarryman, as Sir R. Murchison observes, when speaking of the phenomena, as exhibited in Shropshire and the neighbouring counties, the greatest aid in the extraction of blocks of stone; and, if a sufficient number cross each other, the whole mass of rock is split into symmetrical blocks. The faces of the joints are for the most part smoother and more regular than the surfaces of true strata. The joints are straight-cut chinks, often slightly open, often passing, not only through layers of successive deposition, but also through balls of limestone or other matter which have been formed by concretionary action, since the original accumulation of the strata. Such joints, therefore, must often have resulted from one of the last changes superinduced upon sedimentary deposits.†

In the annexed diagram (fig. 707.), the flat surfaces of rock A, B, C, represent exposed faces of joints, to which the walls of other joints, J J, are parallel. S S are the lines of stratification; D D are lines of slaty cleavage, which intersect the rock at a considerable angle to the planes of stratification.

In the Swiss and Savoy Alps, as Mr. Bakewell has remarked, enormous masses of limestone are cut through so regularly by nearly vertical partings, and these joints are often so much more conspicuous than the seams of stratification, that an inexperienced observer will almost inevitably confound them, and suppose the strata to be perpendicular in places where in fact they are almost horizontal.‡

Now such joints are supposed to be analogous to the partings

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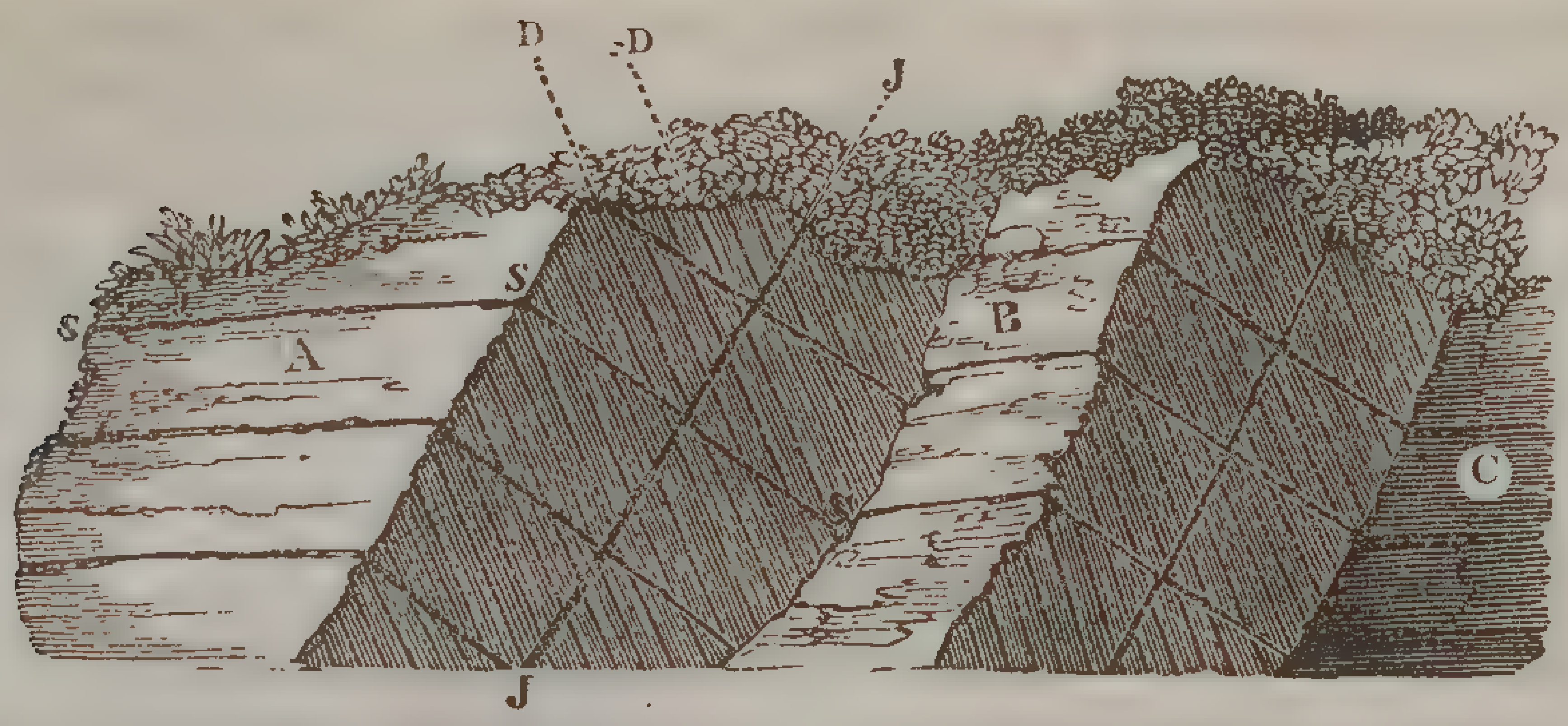
* Geol. Trans., 2d series, vol. iii. p. 461.

† Silurian System, p. 246.

‡ Introduction to Geology, chap. iv.

Fig. 707.



Stratification, joints, and cleavage.
(From Murchison's Silurian System, p. 245.)

which separate volcanic and plutonic rocks into cuboidal and prismatic masses. On a small scale we see clay and starch when dry split into similar shapes; this is often caused by simple contraction, whether the shrinking be due to the evaporation of water, or to a change of temperature. It is well known that many sandstones and other rocks expand by the application of moderate degrees of heat, and then contract again on cooling; and there can be no doubt that large portions of the earth's crust have, in the course of past ages, been subjected again and again to very different degrees of heat and cold. These alternations of temperature have probably contributed largely to the production of joints in rocks.

In some countries, as in Saxony, where masses of basalt rest on sandstone, the aqueous rock has for the distance of several feet from the point of junction assumed a columnar structure similar to that of the trap. In like manner some hearthstones, after exposure to the heat of a furnace without being melted, have become prismatic. Certain crystals also acquire by the application of heat a new internal arrangement, so as to break in a new direction, their external form remaining unaltered.

Professor Sedgwick, speaking of the planes of slaty cleavage, where they are decidedly distinct from those of sedimentary deposition, declared in the essay before alluded to, his opinion that no retreat of parts, no contraction in the dimensions of rocks in passing to a solid state, can account for the phenomenon. He accordingly referred it to crystalline or polar forces acting simultaneously, and somewhat uniformly, in given directions, on large masses having a homogeneous composition.

Sir John Herschel, in allusion to slaty cleavage, has suggested, "that if rocks have been so heated as to allow a commencement of crystallization,—that is to say, if they have been heated to a point at which the particles can begin to move amongst themselves, or at least on their own axes, some general law must then determine the position in which these particles will rest on cooling. Probably, that position will have some relation to the direction in which the heat escapes. Now, when all, or a majority of particles of the same nature have a general tendency to one position, that must of course determine a cleavage-plane. Thus we see the infinitesimal crystals of fresh precipitated sulphate of barytes, and some other such bodies, arrange themselves alike in the fluid in which they float; so as, when stirred, all to glance with one light, and give the appearance of silky filaments. Some sorts of soap, in which insoluble margarates * exist, exhibit the same phenomenon when mixed with water; and what occurs in our experiments on a minute scale may occur in nature on a great one." †

Professor Phillips has remarked that in some slaty rocks the form of the outline of fossil shells and trilobites has been much changed by distortion, which has taken place in a longitudinal, transverse, or oblique direction. This change, he adds, seems to be the result of a "creeping movement" of the particles of the rock along the planes of cleavage, its direction being always uniform over the same tract of country, and its amount in space being sometimes measurable, and being as much as a quarter or even half an inch. The hard shells are not affected, but only those which are thin.‡ Mr. D. Sharpe, following up the same line of inquiry, came to the conclusion, that the present distorted forms of the shells in certain British slate rocks may be accounted for by supposing that the rocks in which they are imbedded have undergone compression in a direction perpendicular to the planes of cleavage, and a corresponding expansion in the direction of the dip of the cleavage.§

More recently (July, 1853) Mr. Sorby has demonstrated the great extent to which this mechanical theory is applicable to the slate rocks of North Wales and Devonshire ‖, districts where the amount of change in dimensions can be tested and measured by comparing the different effects exerted by lateral pressure on alternating beds of finer and coarser materials. Thus, for example, in the accompanying figure (fig. 708.) it will be seen that the sandy bed *d f*, which has offered greater resistance, has been sharply contorted, while the fine-grained strata, *a*, *b*, *c*, have remained comparatively unbent. The points *d* and *f* in the stratum *d f* must have been originally four times as far apart as they are now. They have been forced so much nearer to each other, partly by bending, and partly by becoming elongated in the direction of what may be called the longer axes of their contortions, and lastly, to a certain small amount, by condensation. The chief result has obviously been due to the bending; but, in proof of elongation, it will be observed that the thickness of the bed *d f* is now about four times greater in those parts lying in the main direction of the flexures than in a plane perpen-

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* Margaric acid is an oleaginous acid, formed from different animal and vegetable fatty substances. A margarate is a compound of this acid with soda, potash, or some other base, and is so named from its pearly lustre.

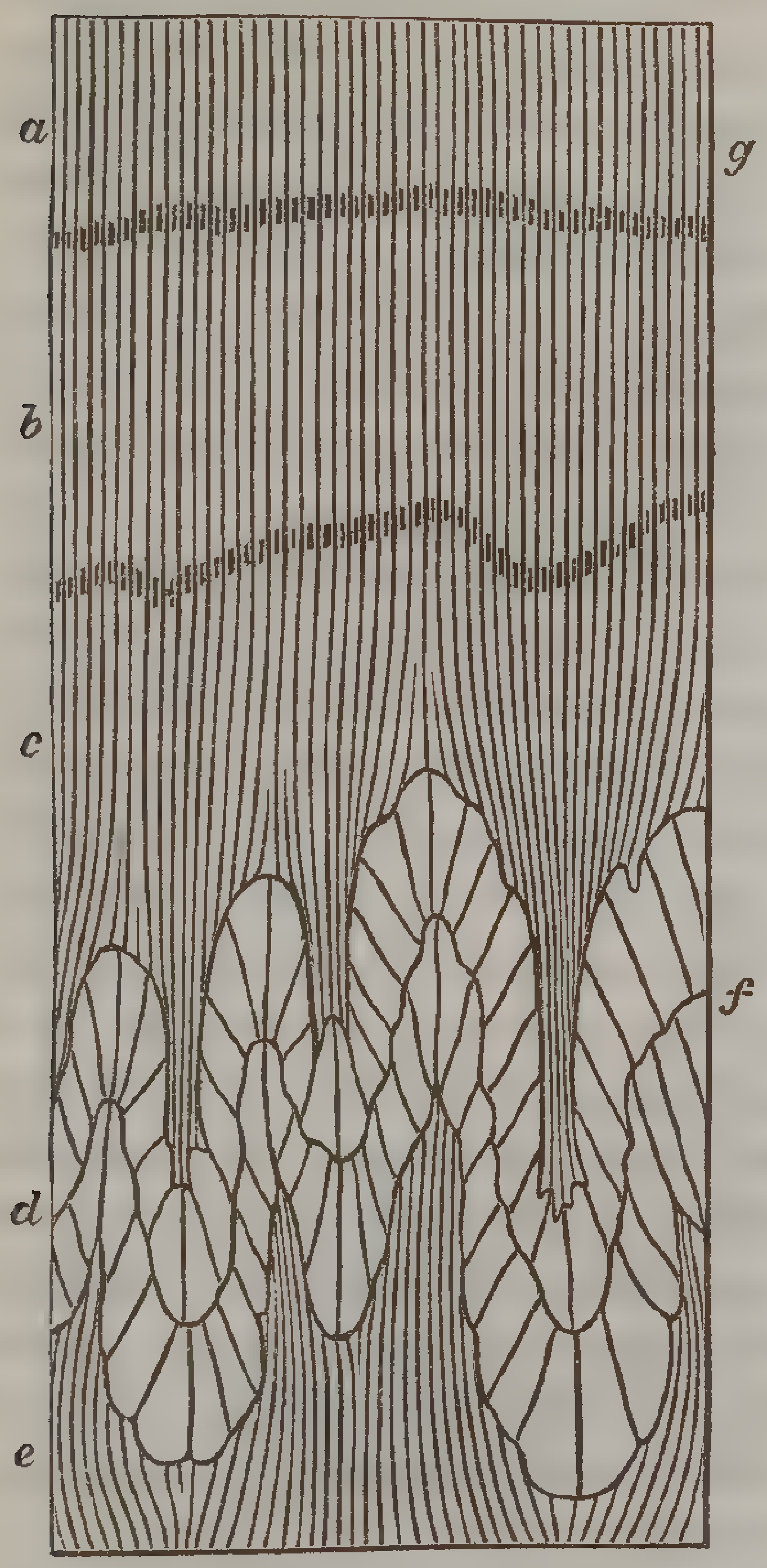
† Letter to the author, dated Cape of Good Hope, Feb. 20. 1836.

‡ Report, Brit. Assoc., Cork, 1843, Sect. p. 60.

§ Quart. Geol. Journ., vol. iii. p. 87. 1847.

‖ On the Origin of Slaty Cleavage, by H. C. Sorby, Edinb. New. Phil. Journ. 1853, vol. lv. p. 137.

Fig. 708.



(Drawn by H. C. Sorby.)

Vertical section of slate rock in the cliffs near Ilfracombe, North Devon.

Scale one inch to one foot.

a, *b*, *c*, *e*. Fine-grained slates, the stratification being shown partly by lighter, or darker colours, and partly by different degrees of fineness in the grain.
d, *f*. A coarser-grained light-coloured sandy slate with less perfect cleavage.

dicular to them; and the same bed exhibits cleavage-planes in the direction of the greatest movement, although they are much fewer than in the slaty strata above and below.

Above the sandy bed *d f*, the stratum *c* is somewhat disturbed, while the next bed *b* is much less so, and *a* not at all; yet all these beds, *c*, *b*, and *a*, must have undergone an equal amount of pressure with *d*, the points *a* and *g* having approximated as much towards each other as have *d* and *f*. The same phenomena are also repeated in the beds below *d*, and might have been shown, had the section been extended downwards. Hence it appears that the finer beds have been squeezed into a fourth of the space they previously occupied, partly by condensation, or the closer packing of their ultimate particles (which has given rise to the great specific gravity of such slates), and partly by elongation in the line of the dip of the cleavage, of which the general direction is perpendicular to that of the pressure. "These and numerous other cases in North Devon are analogous," says Mr. Sorby, "to what would occur if a strip of paper were included in a mass of some soft plastic material which would readily change its dimensions. If the whole were then compressed in the direction of the length of the strip of paper, it would be bent and puckered up into contortions, whilst the plastic material would readily change its dimensions without undergoing such contortions; and the difference in distance of the ends of the paper, as measured in a direct line or along it, would indicate the change in the dimensions of the plastic material."

The student will readily conceive that, when the shape of a fossil or of a crystal of some mineral, or of a spheroidal concretion, has been altered by lateral pressure, the new forms which they assume respectively will vary according to whether they have yielded in one or more directions. They may have been drawn out solely in the direction of the dip of the cleavage, or they may have yielded in a plane perpendicular to that dip, or they may have undergone both these movements. By microscopic examination of minute crystals, and by other observations too minute to be detailed here, Mr. Sorby comes to the conclusion that the absolute condensation of the slate rocks amounts upon an average to about one half their original volume. This must have resulted chiefly from the forcing of the particles more closely together, so as to fill up the spaces left between them, when they only touched each other. The rest of the change has been due to elongation which has produced slaty cleavage.

Most of the scales of mica occurring in certain slates examined by Mr. Sorby lie in the plane of cleavage; whereas in a similar rock not exhibiting cleavage they lie with their longer axes in all directions. May not their position in the slates have been determined by the movement of elongation before alluded to? To illustrate this theory some scales of oxide of iron were mixed with soft pipe-clay in such a manner that they inclined in all directions. The dimensions of the mass were then changed artificially to a similar extent to what has occurred in slate-rocks, and the pipe-clay was then dried and baked. When it was afterwards rubbed to a flat surface perpendicular to the pressure and in the line of elongation, or in a plane corresponding to that of the dip of cleavage, the particles were found to have become arranged in the same manner as in natural slates, and the mass admitted of easy fracture into thin flat pieces in the plane alluded to, whereas it would not yield in that perpendicular to the cleavage.*

This experiment may lend countenance to the opinion that the lamination of basalt and trachyte, and even of some kinds of gneiss, and the grain of certain granites, may all have been determined by a mechanical cause, a movement having taken place after the development of crystals in the pasty-mass.

Mr. Scrope, in his description of the Ponza Islands, ascribed "the zoned structure of the Hungarian perlite (a semi-vitreous trachyte) to its having subsided, in obedience to the impulse of its own gravity, down a slightly inclined plane, while possessed of an imperfect fluidity. In the islands of Ponza and Palmarola, the direction of the zones is more frequently vertical than horizontal, because the mass was impelled from below upwards."† In like manner, Mr. Darwin attributes the lamination and fissile structure of volcanic rocks of the trachytic series, including some obsidians in Ascension, Mexico, and elsewhere, to their having moved when liquid in the direction of the laminæ. The zones consist sometimes of layers of air-cells drawn out and lengthened in the supposed direction of the moving mass. He compares this division into parallel zones, thus caused by the stretching of a pasty mass as it flowed slowly onwards, to the zoned or ribboned structure of ice, which Professor

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* Sorby, as cited above, p. 610, note.

† Geol. Trans. 2d. ser. vol. ii. p. 227.

James Forbes has so ably explained, showing that it is due to the fissuring of a viscous body in motion.*

Whatever be the cause, the result, observes Darwin, is well worthy the attention of geologists; for in a volcanic rock of the trachytic series in Ascension layers are seen often of extreme tenuity, even as thin as hairs, and of different colours, alternating again and again, some of them composed of crystals of quartz and diopside (a kind of augite), others of black augitic specks with granules of oxide of iron, and lastly, others of crystalline felspar. It is supposed in this case that the crystallizing force acted more freely in the direction of the planes of cleavage, produced when the pasty mass was stretched, whether because confined vapours were enabled to spread themselves through the minute fissures, or because the ultimate molecules had more freedom of motion along the planes of less tension, or for some other reasons not yet understood.

After studying, in 1835, the crystalline rocks of South America, Mr. Darwin proposed the term *foliation* for the laminæ or plates into which gneiss, mica-schist, and other crystalline rocks are divided. Cleavage, he observes, may be applied to those divisional planes which render a rock fissile, although it may appear to the eye quite or nearly homogeneous. Foliation may be used for those alternating layers or plates of different mineralogical nature of which gneiss and other metamorphic schists are composed. The cleavage planes of the clay-slate in Terra del Fuego and Chili preserve a uniform strike for hundreds of miles in regions where these planes are quite distinct from stratification. In the same country the planes of foliation of the mica-schist and gneiss are parallel to the cleavage of the clay-slate. Hence, we are tempted, at first sight, to infer that some common cause or process, and that cause not connected with sedimentary deposition, has impressed cleavage on the one set of rocks and foliation on the other. But such an inference can only be legitimately drawn in those rare cases where we are able, by a continuous section, to prove that not only the strike, but the dip of the slaty cleavage on the one hand, and of the foliation on the other, precisely coincide; the cleavage at the same time not being parallel to the stratification in the slate rock. In some examples cited by Mr. Darwin, in Terra del Fuego, the Chonos Islands, and La Plata, this uniformity of dip seems to have been traced in a manner as satisfactory as the nature of such evidence will allow. But we must be on our guard against a source of deception which may mislead us in this chain of reasoning. We are informed that in South America, as in other countries, the strike of the cleavage in clay-slate conforms to the axis of elevation of the rocks in the same districts. Hence it must follow that the *folia* of gneiss, mica-schist, limestone, and other crystalline rocks, even if they strictly coincide with the planes of original stratification, will run in the

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* Darwin, Volcanic Islands, pp. 69, 70.

same direction as the strike of the slaty cleavage; for the true strata always dip at right angles to the axis of elevation, and are parallel to it in their strike. No argument, therefore, can be drawn in favour of a common origin from uniformity of strike in the slaty and foliated rocks; for we require, in addition, coincidence of dip; and such is the variability of the dip both of the slates and folia as to render this kind of proof very difficult to obtain.

That the foliation of the crystalline schists in Norway accords very generally with the planes of original stratification is a conclusion long since espoused by Keilhau.* Numerous observations made by Mr. David Forbes in the same country (the best probably in Europe for studying such phenomena on a grand scale) confirm Keilhau's opinion; for the dip of the Silurian and fossiliferous strata where they pass into the metamorphic agrees with the foliation of the contiguous gneiss, mica-schist, and crystalline limestone. So also in Scotland Mr. D. Forbes has pointed out a striking case where the foliation is identical with the lines of stratification in rocks well seen near Crianlorich on the road to Tyndrum, about 8 miles from Inverarnon in Perthshire. There is in that locality a blue limestone foliated by the intercalation of small plates of white mica, so that the rock is often scarcely distinguishable in aspect from gneiss or mica-schist. The stratification is shown by the large beds and coloured bands of limestone all dipping, like the folia, at an angle of 32 degrees N. E.†

In stratified formations of every age we see layers of siliceous sand with or without mica, alternating with clay, with fragments of shells or corals, or with seams of vegetable matter, and we should expect the mutual attraction of like particles to favour the crystallization of the quartz, or mica, or felspar, or carbonate of lime, along the planes of original deposition, rather than in planes placed at angles of 20 or 40 degrees to those of stratification.

In Patagonia, a series of thin sedimentary layers of tuff were observed by Mr. Darwin to have become porphyritic, first where least altered, by a process of aggregation, small patches of clay appearing to be shortened into almond-shaped concretions, which in those places where they were more changed had become crystals of felspar, having their longer axes parallel to each other. In other associated strata, grains of quartz had in like manner aggregated into nodules of crystalline quartz.‡

May we not, then, presume that in rocks where no cleavage has intervened, foliation and the planes of stratification will usually coincide, as in all cases where cleavage happens (as in the writing-slates of the Niesen on the Lake of Thun in Switzerland, containing fucoids) to agree with the original planes of sedimentary deposition? Mr. Darwin conceives that "foliation may be the extreme result of

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* Norske Mag. Naturvidsk., vol. i. p. 71.

† Memoir read before the Geol. Soc., London, Jan. 31. 1855.

‡ South America, p. 149.

the process of which cleavage is the first effect;" or, at any rate, that the crystalline force may have been most energetic in the direction of cleavage. As bearing on this view, he says, "I was particularly struck in the eastern parts of Terra del Fuego with the fact that the fine laminæ of clay-slate, where they cut straight through the bands of stratification, and therefore indisputably true cleavage-planes, differ slightly from one another in their greyish and greenish tints of colour, as also in their compactness, and in some laminæ having a more jaspery appearance than others. This fact shows that the same cause which has produced the highly fissile structure has altered in a slight degree the mineralogical character of the rock in the same planes."* As one step farther towards tracing a passage from planes of cleavage to those of foliation, Professor Sedgwick observes that in North Wales the surfaces of slates are sometimes coated over with chlorite, "the crystals of which have not only defined the cleavage planes but struck through the whole mass of the rock."† So also, says Mr. Darwin, in some places in South America crystals of epidote and of mica coat the planes of cleavage.

Mr. D. Sharpe inferred from observations made by him in the Highlands of Scotland, in 1851, that the foliation of the gneiss and mica-schist are upon the whole parallel to one another, but have no connection with any original planes of stratification; and he also conceives that the planes both of cleavage and foliation in the Grampians and in the region of Mont Blanc in Switzerland (which last he examined in 1854) are parts of great curves or anticlinal axes of considerable regularity.‡ In like manner in South America the cleavage planes of the clay-slate had been suspected by Mr. Darwin, notwithstanding their varying and opposite dips, to be parts of large curves or foldings, having their summits cut off and worn down.§

There seems to be no difficulty in imagining that in rocks of *homogeneous* composition the foliation may take place along planes previously caused by the elongation of the materials along the dip of the cleavage; for experienced geologists have been at a loss to decide in many countries which of two sets of divisional planes were referable to cleavage, and which to stratification; and after much doubt, have discovered that they had at first mistaken the lines of cleavage for those of deposition, because the former were by far the most marked of the two. Now if such slaty masses should become highly crystalline, and be converted into gneiss, hornblende-schist, or any other member of the hypogene class, the cleavage planes would be more likely to remain visible than those of stratification. Professor Henslow had noticed, so long ago as the year 1821, that

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* Geol. Observ. on South America, p. 155.

† Sedgwick, Geol. Trans. 2d ser. vol. iii. p 471.

‡ D. Sharpe, Phil. Trans., 1852, and Geol. Quart. Journ., no. 41. 1855.

§ Darwin, S. America, p. 155.

the lamination of the chloritic and other crystalline schists in Anglesea was approximately in the planes of bedding; and Professor Ramsay, in 1841, observed the same in regard to the gneiss and mica-schist of Arran. The last-cited geologist says, in reference to Anglesea, that the metamorphism probably took place when the Lower Silurian volcanos were in activity, and therefore long before the cleavage of the Welsh rocks; for the cleavage of the latter affects in common the Lower Silurian and the Cambrian strata. In the same memoir he adds, when referring to Mr. Darwin's theory of foliation, "that if the rocks be uncleaved when metamorphism occurs, the foliation planes will be apt to coincide with those of bedding; but if intense cleavage has preceded, then we may expect that the planes of foliation will lie in the planes of cleavage."*

From what I have myself seen in the Grampians, both in Forfarshire and Perthshire, I have always concluded that Macculloch was correct in the opinion that gneiss and mica-schist may be considered as stratified rocks, and that certain beds of pure quartz, one or two feet thick, which run for miles in the strike of their foliation, as well as the intercalation of masses of limestone, and of chloritic, actinolitic, and hornblende schists, all indicate the planes of original stratification. At the same time, I fully admit that the alternate layers of quartz, or of mica and quartz, of felspar, or of mica and felspar, or of carbonate of lime, are more distinct, in certain metamorphic rocks, than the ingredients composing alternate layers in most sedimentary deposits, so that similar particles must be supposed to have exerted a molecular attraction for each other, and to have congregated together in layers more distinct in mineral composition than before they were crystallized.

We have seen how much the original planes of stratification may be interfered with or even obliterated by concretionary action in deposits still retaining their fossils, as in the case of the magnesian limestone (see p. 37.). Hence we must expect to be frequently baffled when we attempt to decide whether the foliation does or does not accord with that arrangement which gravitation, combined with current-action, imparted to a deposit from water. Moreover, when we look for stratification in crystalline rocks, we must be on our guard not to expect too much regularity. The occurrence of wedge-shaped masses, such as belong to coarse sand and pebbles,—diagonal lamination (see p. 16.),—ripple-mark,—unconformable stratification (p. 61.),—the fantastic folds produced by lateral pressure,—faults of various width,—intrusive dikes of trap,—organic bodies of diversified shapes,—and other causes of unevenness in the planes of deposition, both on the small and on the large scale, will interfere with parallelism. If complex and enigmatical appearances did not present themselves, it would be a serious objection to the metamorphic theory.

In the accompanying diagram I have represented carefully the

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* Geol. Quart. Journ., 1853, vol. ix. p. 172.

Fig. 709.

Lamination of clay-slate, Montagne de Seguinat, near Gavarnie, in the Pyrenees.

lamination of a coarse argillaceous schist which I examined in 1830 in the Pyrenees. In part it approaches in character to a green and blue roofing-slate, while part is extremely quartzose, the whole mass passing downwards into micaceous schist. The vertical section here exhibited is about 3 feet in height, and the layers are sometimes so thin that fifty may be counted in the thickness of an inch. Some of them consist of pure quartz.

There is a resemblance in such cases to the diagonal lamination which we see in sedimentary rocks, even though the layers of quartz and of mica, or of felspar and other minerals may be more distinct in alternating folia than they were originally.

M. Elie de Beaumont, while he regards the greater part of the gneiss and mica-schist of the Alps as sedimentary strata altered by plutonic action, still conceives that some of the Alpine gneiss may have been erupted, or, in other words, may be granite drawn out into parallel laminæ in the manner of trachyte as above alluded to.*

If the mass were squeezed and elongated in a certain direction after crystals of mica, talc, or other scaly minerals were developed, these may perhaps have arranged themselves in planes parallel to those of movement, and a similar process may account for what the quarrymen call "the grain" in some granites, or a tendency to split in one direction more freely than in another. But, as a general rule, the fusion of the crystalline schists does not appear to have gone so far as to allow of motion analogous to that of lava or granite, and for this reason rocks of this class do not send veins into surrounding rocks. In the next chapter we may inquire at how many distinct periods the hypogene or metamorphic schists can be proved to have originated, and why for so long a time the earlier geologists regarded them as entitled to the name of "primitive."

* Bulletin Soc. Geol. de France, 2e sér. vol. iv. p. 1301.

CHAPTER XXXVII.

ON THE DIFFERENT AGES OF THE METAMORPHIC ROCKS.

Age of each set of metamorphic strata twofold — Test of age by fossils and mineral character not available — Test by superposition ambiguous — Conversion of dense masses of fossiliferous strata into metamorphic rocks — Limestone and shale of Carrara — Metamorphic strata of older date than the Cambrian rocks — Others of Lower Silurian origin — Others of the Jurassic and Eocene periods in the Alps of Switzerland and Savoy — Why scarcely any of the visible crystalline strata are very modern — Order of succession in metamorphic rocks — Uniformity of mineral character — Why the metamorphic strata are less calcareous than the fossilferous.

According to the theory adopted in the last chapter, the age of each set of metamorphic strata is twofold, — they have been deposited at one period, they have become crystalline at another. We can rarely hope to define with exactness the date of both these periods, the fossils having been destroyed by plutonic action, and the mineral characters being the same, whatever the age. Superposition itself is an ambiguous test, especially when we desire to determine the period of crystallization. Suppose, for example, we are convinced that certain metamorphic strata in the Alps, which are covered by cretaceous beds, are altered lias; this lias may have assumed its crystalline texture in the cretaceous or in some tertiary period, the Eocene for example. If in the latter, it should be called Eocene when regarded as a metamorphic rock, although it be liassic when considered in reference to the era of its deposition. According to this view, the superposition of chalk does not prevent the subjacent *metamorphic* rock from being Eocene.

When discussing the ages of the plutonic rocks, we have seen that examples occur of various primary, secondary, and tertiary deposits converted into metamorphic strata, near their contact with granite. There can be no doubt in these cases that strata, once composed of mud, sand, and gravel, or of clay, marl, and shelly limestone, have for the distance of several yards, and in some instances several hundred feet, been turned into gneiss, mica-schist, hornblende-schist, chlorite-schist, quartz rock, statuary marble, and the rest. (See the two preceding Chapters.)

But when the metamorphic action has operated on a grander scale, it tends entirely to destroy all monuments of the date of its development. It may be easy to prove the identity of two different parts of the same stratum; one, where the rock has been in contact with a volcanic or plutonic mass, and has been changed into marble or hornblende-schist, and another not far distant, where the same bed remains unaltered and fossiliferous; but when we have to compare two portions of a mountain chain — the one metamorphic, and the other unaltered — all the labour and skill of the most practised observers are required, and may sometimes be at fault. I shall mention one or two examples of alteration on a grand scale, in order to explain to the student the kind of reasoning by which we are led to infer that dense masses of fossiliferous strata have been converted into crystalline rocks.

Northern Apennines — Carrara. — The celebrated marble of Carrara, used in sculpture, was once regarded as a type of primitive limestone. It abounds in the mountains of Massa Carrara, or the "Apuan Alps," as they have been called, the highest peaks of which are nearly 6000 feet high. Its great antiquity was inferred from its mineral texture, from the absence of fossils, and its passage downwards into talc-schist and garnetiferous mica-schist; these rocks again graduating downwards into gneiss, which is penetrated, at Forno, by granite veins. Now the researches of MM. Savi, Boué, Pareto, Guidoni, De la Beche, Hoffmann, and Pilla have demonstrated that this marble, once supposed to be formed before the existence of organic beings, is, in fact, an altered limestone of the Oolitic period, and the underlying crystalline schists are secondary sandstones and shales, modified by plutonic action. In order to establish these conclusions, it was first pointed out, that the calcareous rocks bordering the Gulf of Spezia, and abounding in Oolitic fossils, assume a texture like that of Carrara marble, in proportion as they are more and more invaded by certain trappean and plutonic rocks, such as a diorite, euphotide, serpentine, and granite, occurring in the same country.

It was then observed that, in places where the secondary formations are unaltered, the uppermost consist of common Apennine limestone with nodules of flint, below which are shales, and at the base of all, argillaceous and siliceous sandstones. In the limestone fossils are frequent, but very rare in the underlying shale and sandstone. Then a gradation was traced laterally from these rocks into another and corresponding series, which is completely metamorphic; for at the top of this we find a white granular marble, wholly devoid of fossils, and almost without stratification, in which there are no nodules of flint, but in its place siliceous matter disseminated through the mass in the form of prisms of quartz. Below this, and in place of the shales, are talc-schists, jasper, and hornstone; and at the bottom, instead of the siliceous and argillaceous sandstones, are quartzite and gneiss.* Had these secondary strata of the Apennines undergone universally as great an amount of transmutation, it would have been impossible to form a conjecture respecting their true age; and then, according to the method of classification adopted by the

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* See notices of Savi, Hoffmann, and others, referred to by Boué, Bull. de la Soc. Géol. de France, tom. v. p. 317.; and tom. iii. p. xliv.; also Pilla, cited by Murchison, Quart. Geol. Journ. vol. v. p. 266.

earlier geologists they would have ranked as primary rocks. In that case the date of their origin would have been thrown back to an era antecedent to the deposition of the Lower Silurian or Cambrian strata, although in reality they were formed in the Oolitic period, and altered at some subsequent and perhaps much later epoch.

Alps of Switzerland.—In the Alps, analogous conclusions have been drawn respecting the alteration of strata on a still more extended scale. In the eastern part of that chain, some of the primary fossiliferous strata, as well as the older secondary formations, together with the oolitic and cretaceous rocks, are distinctly recognizable. Tertiary deposits also appear in a less elevated position on the flanks of the Eastern Alps; but in the Central or Swiss Alps, the primary fossiliferous and older secondary formations disappear, and the Cretaceous, Oolitic, Liassic, and at some points even the Eocene strata, graduate insensibly into metamorphic rocks, consisting of granular limestone, talc-schist, talcose-gneiss, micaceous schist, and other varieties. In regard to the age of this vast assemblage of crystalline strata, we can merely affirm that some of the upper portions are altered newer secondary, and some of them even Eocene deposits; but we cannot avoid suspecting that the disappearance both of the older secondary and primary fossiliferous rocks may be owing to their having been all converted in the same region into crystalline schist.

It is difficult to convey to those who have never visited the Alps a just idea of the various proofs which concur to produce this conviction. In the first place, there are certain regions where Oolitic, Cretaceous, and Eocene strata have been turned into granular marble, gneiss, and other metamorphic schists, near their contact with granite. This fact shows undeniably that plutonic causes continued to be in operation in the Alps down to a late period, even after the deposition of some of the nummulitic or middle Eocene formations. Having established this point, we are the more willing to believe that many inferior fossiliferous rocks, probably exposed for longer periods to a similar action, may have become metamorphic to a still greater extent.

We also discover in parts of the Swiss Alps dense masses of secondary and even tertiary strata which have assumed that semicrystalline texture which Werner called transition, and which naturally led his followers, who attached great importance to mineral characters taken alone, to class them as transition formations, or as groups older than the lowest secondary rocks. (See p. 93.). Now, it is probable that these strata have been affected, although in a less intense degree, by that same plutonic action which has entirely altered and rendered metamorphic so many of the subjacent formations; for in the Alps, this action has by no means been confined to the immediate vicinity of granite. Granite, indeed, and other plutonic rocks, rarely make their appearance at the surface, notwithstanding the deep ravines which lay open to view the internal structure of these mountains. That they exist below at no great depth we cannot doubt, and we have already seen (p. 574.) that at some points, as in the Valorsine, near Mont Blanc, granite and granitic veins are observable, piercing through talcose gneiss, which passes insensibly upwards into secondary strata.

It is certainly in the Alps of Switzerland and Savoy, more than in any other district in Europe, that the geologist is prepared to meet with the signs of an intense development of plutonic action; for here we find the most stupendous monuments of mechanical violence, by which strata thousands of feet thick have been bent, folded, and overturned. (See p. 58.) It is here that marine secondary formations of a comparatively modern date, such as the Oolitic and Cretaceous, have been upheaved to the height of 12,000, and some Eocene strata to elevations of 10,000 feet above the level of the sea; and even deposits of the Miocene era have been raised 4000 or 5000 feet, so as to rival in height the loftiest mountains in Great Britain.

If the reader will consult the works of many eminent geologists who have explored the Alps, especially those of MM. de Beaumont, Studer, Necker, Boué, and Murchison, he will learn that they all share, more or less fully, in the opinions above expressed. It has, indeed, been stated by MM. Studer and Hugi, that there are complete alternations on a large scale of secondary strata, containing fossils, with gneiss and other rocks of a perfectly metamorphic structure. I have visited some of the most remarkable localities referred to by these authors; but although agreeing with them that there are passages from the fossiliferous to the metamorphic series far from the contact of granite or other plutonic rocks, I was unable to convince myself that the distinct alternations of highly crystalline, with unaltered strata above alluded to, might not admit of a different explanation. In one of the sections described by M. Studer in the highest of the Bernese Alps, namely in the Roththal, a valley bordering the line of perpetual snow on the northern side of the Jungfrau, there occurs a mass of gneiss 1000 feet thick, and 15,000 feet long, which I examined, not only resting upon, but also again covered by strata containing oolitic fossils. These anomalous appearances may partly be explained by supposing great solid wedges of intrusive gneiss to have been forced in laterally between strata to which I found them to be in many sections unconformable. The superposition, also, of the gneiss to the oolite may, in some cases, be due to a reversal of the original position of the beds in a region where the convulsions have been on so stupendous a scale.

On the Sattel also, at the base of the Gestellihorn, above Enzen, in the valley of Urbach, near Meyringen, some of the intercalations of gneiss between fossiliferous strata may, I conceive, be ascribed to mechanical derangement. Almost any hypothesis of repeated changes of position may be resorted to in a region of such extraordinary confusion. The secondary strata may first have been vertical, and then certain portions may have become metamorphic (the plutonic influence ascending from below), while intervening strata remained unchanged. The whole series of beds may then again have been thrown into a nearly horizontal position, giving rise to the superposition of crystalline upon fossiliferous formations.

It was remarked, in Chap. XXXIV., that as the hypogene rocks, both stratified and unstratified, crystallize originally at a certain depth beneath the surface, they must always, before they are upraised and exposed at the surface, be of considerable antiquity, relatively to a large portion of the fossiliferous and volcanic rocks. They may be forming at all periods; but before any of them can become visible, they must be raised above the level of the sea, and some of the rocks which previously concealed them must have been removed by denudation.

In Canada the fossiliferous beds of the Cambrian formation repose unconformably on gneiss, which was evidently crystalline before the deposition of the Cambrian (or Potsdam) sandstone. In Anglesea, as was before remarked, the metamorphism of the schists, according to the observations of Professor Ramsay, took place during the Lower Silurian period. Coupling these conclusions with the fact that a hypogene texture has been superinduced in the Alps on Middle Eocene deposits (see p. 606.), we cannot doubt that, hereafter, geologists will succeed in detecting crystalline schists of almost every age in the chronological series, although the quantity of metamorphic rocks visible at the surface must, for reasons above explained, diminish rapidly in proportion as the monuments of newer eras are investigated.

Order of succession in metamorphic rocks.—There is no universal and invariable order of superposition in metamorphic rocks, although a particular arrangement may prevail throughout countries of great extent, for the same reason that it is traceable in those sedimentary formations from which crystalline strata are derived. Thus, for example, we have seen that in the Apennines, near Carrara, the descending series, where it is metamorphic, consists of, 1st, saccharine marble; 2ndly, talcose-schist; and 3rdly, of quartz-rock and gneiss: where unaltered, of, 1st, fossiliferous limestone; 2ndly, shale; and 3rdly, sandstone.

But if we investigate different mountain chains, we find gneiss, mica-schist, hornblende-schist, chlorite-schist, hypogene limestone, and other rocks, succeeding each other, and alternating with each other in every possible order. It is, indeed, more common to meet with some variety of clay-slate forming the uppermost member of a metamorphic series than any other rock; but this fact by no means implies, as some have imagined, that all clay-slates were formed at the close of an imaginary period, when the deposition of the crystalline strata gave way to that of ordinary sedimentary deposits. Such clay-slates, in fact, are variable in composition, and sometimes alternate with fossiliferous strata, so that they may be said to belong almost equally to the sedimentary and metamorphic order of rocks. It is probable that had they been subjected to more intense plutonic action, they would have been transformed into hornblende-schist, foliated chlorite-schist, scaly talcose-schist, mica-schist, or other more perfectly crystalline rocks, such as are usually associated with gneiss.

Uniformity of mineral character in Hypogene rocks.—Humboldt has emphatically remarked, that when we pass to another hemisphere, we see new forms of animals and plants, and even new constellations in the heavens; but in the rocks we still recognise our old acquaintances,—the same granite, the same gneiss, the same micaceous schist, quartz-rock, and the rest. It is certainly true that there is a great and striking general resemblance in the principal kinds of hypogene rocks, although of very different ages and countries; but it has been shown that each of these are, in fact, geological families of rocks, and not definite mineral compounds. They are much more uniform in aspect than sedimentary strata, because these last are often composed of fragments varying greatly in form, size, and colour, and contain fossils of different shapes and mineral composition, and acquire a variety of tints from the mixture of various kinds of sediment. The materials of such strata, if melted and made to crystallize, would be subject to chemical laws, simple and uniform in their action, the same in every climate, and wholly undisturbed by mechanical and organic causes.

Nevertheless, it would be a great error to assume that the hypogene rocks, considered as aggregates of simple minerals, are really more homogeneous in their composition than the several members of the sedimentary series. In the first place, different assemblages of hypogene rocks occur in different countries; and, secondly, in any one district, the rocks which pass under the same name are often extremely variable in their component ingredients, or at least in the proportions in which each of these are present. Thus, for example, gneiss and mica-schist, so abundant in the Grampians, are wanting in Cumberland, Wales, and Cornwall; in parts of the Swiss and Italian Alps, the gneiss and granite are talcose, and not micaceous, as in Scotland; hornblende prevails in the granite of Scotland—schorl in that of Cornwall—albite in the plutonic rocks of the Andes—common felspar in those of Europe. In one part of Scotland, the mica-schist is full of garnets; in another it is wholly devoid of them; while in South America, according to Mr. Darwin, it is the gneiss, and not the mica-schist, which is most commonly garnetiferous. And not only do the proportional quantities of felspar, quartz, mica, hornblende, and other minerals, vary in hypogene rocks bearing the same name; but what is still more important, the ingredients, as we have seen, of the same simple mineral are not always constant (p. 467., and table, p. 105.).

The Metamorphic strata, why less calcareous than the fossiliferous.—It has been remarked, that the quantity of calcareous matter in metamorphic strata, or, indeed, in the hypogene formations generally, is far less than in fossiliferous deposits. Thus the crystalline schists of the Grampians in Scotland, consisting of gneiss, mica-schist, hornblende-schist, and other rocks, many thousands of yards in thickness, contain an exceedingly small proportion of interstratified calcareous beds, although these have been the objects of careful search for economical purposes. Yet limestone is not wanting in the Grampians, and it is associated sometimes with gneiss, sometimes with mica-schist, and in other places with other members of the metamorphic series. But where limestone occurs abundantly, as at Carrara, and in parts of the Alps, in connection with hypogene rocks, it usually forms one of the superior members of the crystalline group.

The scarcity, then, of carbonate of lime in the plutonic and metamorphic rocks generally seems to be the result of some general cause. So long as the hypogene rocks were believed to have originated antecedently to the creation of organic beings, it was easy to impute the absence of lime to the non-existence of those mollusca and zoophytes by which shells and corals are secreted; but when we ascribe the crystalline formations to plutonic action, it is natural to inquire whether this action itself may not tend to expel carbonic acid and lime from the materials which it reduces to fusion or semi-fusion. Although we cannot descend into the subterranean regions where volcanic heat is developed, we can observe in regions of spent volcanos, such as Auvergne and Tuscany, hundreds of springs, both cold and thermal, flowing out from granite and other rocks, and having their waters plentifully charged with carbonate of lime. The quantity of calcareous matter which these springs transfer, in the course of ages, from the lower parts of the earth's crust to the superior or newly formed parts of the same, must be considerable.*

If the quantity of siliceous and aluminous ingredients brought up by such springs were great, instead of being utterly insignificant, it might be contended that the mineral matter thus expelled implies simply the decomposition of ordinary subterranean rocks; but the prodigious excess of carbonate of lime over every other element must in the course of time, cause the crust of the earth below to be almost entirely deprived of its calcareous constituents, while we know that the same action imparts to newer deposits, ever forming in seas and lakes, an excess of carbonate of lime. Calcareous matter is poured into these lakes and the ocean by a thousand springs and rivers; so that part of almost every new calcareous rock chemically precipitated, and of many reefs of shelly and coralline stone, must be derived from mineral matter subtracted by plutonic agency, and driven up by gas and steam from fused and heated rocks in the bowels of the earth.

Not only carbonate of lime, but also free carbonic acid gas is given off plentifully from the soil and crevices of rocks in regions of active and spent volcanos as near Naples and in Auvergne. By this process, fossil shells or corals may often lose their carbonic acid, and the residual lime may enter into the composition of augite, hornblende, garnet, and other hypogene minerals. That the removal of the calcareous matter of fossil shells is of frequent occurrence, is proved by the fact of such organic remains being often replaced by silex or

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* See Principles of Geology by the Author, *Index*, "Calcareous Springs."

other minerals, and sometimes by the space once occupied by the fossil being left empty, or only marked by a faint impression. We ought not indeed to marvel at the general absence of organic remains from the crystalline strata, when we bear in mind how often fossils are obliterated, wholly or in part, even in tertiary formations —how often vast masses of sandstone and shale, of different ages, and thousands of feet thick, are devoid of fossils—how certain strata may first have been deprived of a portion of their fossils when they became semi-crystalline, or assumed the *transition* state of Werner —and how the remaining portion may have been effaced when they were rendered metamorphic. Rocks of the last-mentioned class, moreover, have sometimes been exposed again and again to renewed plutonic action.

CHAPTER XXXVIII.

MINERAL VEINS.

Werner's doctrine that mineral veins were fissures filled from above—Veins of segregation—Ordinary metalliferous veins or lodes—Their frequent coincidence with faults—Proofs that they originated in fissures in solid rock—Veins shifting other veins—Polishing of their walls or "slicken-sides."—Shells and pebbles in lodes—Evidence of the successive enlargement and reopening of veins—Fournet's observations in Auvergne—Dimensions of veins—Why some alternately swell out and contract—Filling of lodes by sublimation from below—Chemical and electrical action—Relative age of the precious metals—Copper and lead veins in Ireland older than Cornish tin—Lead vein in lias, Glamorganshire—Gold in Russia, California, and Australia.—Connection of hot springs and mineral veins—Concluding remarks.

THE manner in which metallic substances are distributed through the earth's crust, and more especially the phenomena of those nearly vertical and tabular masses of ore called mineral veins, from which the larger part of the precious metals used by man are obtained,—these are subjects of the highest practical importance to the miner, and of no less theoretical interest to the geologist.

The views entertained respecting metalliferous veins have been modified, or, rather, have undergone an almost complete revolution, since the middle of the last century, when Werner, as director of the School of Mines, at Freiburg in Saxony, first attempted to generalize the facts then known. He taught that mineral veins had originally been open fissures which were gradually filled up with crystalline and metallic matter, and that many of them, after being once filled, had been again enlarged or reopened. He also pointed out that veins thus formed are not all referable to one era, but are of various geological dates.

Such opinions, although slightly hinted at by earlier writers, had never before been generally received, and their announcement by one of high authority and great experience constituted an era in the science. Nevertheless, I have shown, when tracing, in another work, the history and progress of geology, that Werner was far behind some of his predecessors in his theory of the volcanic rocks, and less enlightened than his contemporary, Dr. Hutton, in his speculations as to the origin of granite.* According to him, the plutonic formations, as well as the crystalline schists, were substances precipitated from a chaotic fluid in some primeval or nascent condition of the planet;

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* Principles of Geology, chap. iv.

and the metals, therefore, being closely connected with them, had partaken, according to him, of a like mysterious origin. He also held that the trap rocks were aqueous deposits, and that dikes of porphyry, greenstone, and basalt, were fissures filled with their several contents from above. Hence he naturally inferred that mineral veins had derived their component materials from an incumbent ocean, rather than from a subterranean source; that these materials had been first dissolved in the waters above, instead of having risen up by sublimation from lakes and seas of igneous matter below.

In proportion as the hypothesis of a primeval fluid, or "chaotic menstruum," was abandoned, in reference to the plutonic formations, and when all geologists had come to be of one mind as to the true relation of the volcanic and trappean rocks, reasonable hopes began to be entertained that the phenomena of mineral veins might be explained by known causes, or by chemical, thermal, and electrical agency still at work in the interior of the earth. The grounds of this conclusion will be better understood when the geological facts brought to light by mining operations have been described and explained.

On different kinds of mineral veins.—Every geologist is familiarly acquainted with those veins of quartz which abound in hypogene strata, forming lenticular masses of limited extent. They are sometimes observed, also, in sandstones and shales. Veins of carbonate of lime are equally common in fossiliferous rocks, especially in limestones. Such veins appear to have once been chinks or small cavities, caused, like cracks in clay, by the shrinking of the mass, which has consolidated from a fluid state, or has simply contracted its dimensions in passing from a higher to a lower temperature. Siliceous, calcareous, and occasionally metallic matters have sometimes found their way simultaneously into such empty spaces, by infiltration from the surrounding rocks, or by segregation, as it is often termed. Mixed with hot water and steam, metallic ores may have permeated a pasty matrix until they reached those receptacles formed by shrinkage, and thus gave rise to that irregular assemblage of veins, called by the Germans a "stockwerk," in allusion to the different floors on which the mining operations are in such cases carried on.

The more ordinary or regular veins are usually worked in vertical shafts, and have evidently been fissures produced by mechanical violence. They traverse all kinds of rocks, both hypogene and fossiliferous, and extend downwards to indefinite or unknown depths. We may assume that they correspond with such rents as we see caused from time to time by the shock of an earthquake. Metalliferous veins, referable to such agency, are occasionally a few inches wide, but more commonly 3 or 4 feet. They hold their course continuously in a certain prevailing direction for miles or leagues, passing through rocks varying in mineral composition.

That metalliferous veins were fissures.—As some intelligent miners, after an attentive study of metalliferous veins, have been unable to reconcile many of their characteristics with the hypothesis of fissures, I shall begin by stating the evidence in its favour. The most striking fact perhaps which can be adduced in its support is, the coincidence of a considerable proportion of mineral veins with *faults*, or those dislocations of rocks which are indisputably due to mechanical force, as above explained (p. 61.). There are even proofs in almost every mining district of a succession of faults, by which the opposite walls of rents, now the receptacles of metallic substances, have suffered displacement. Thus, for example, suppose *a a*, fig. 710., to be a tin lode in Cornwall, the term *lode* being applied to veins containing metallic ores. This lode, running east and west, is a yard wide, and is shifted by a copper lode (*b b*), of similar width.

Fig. 710.

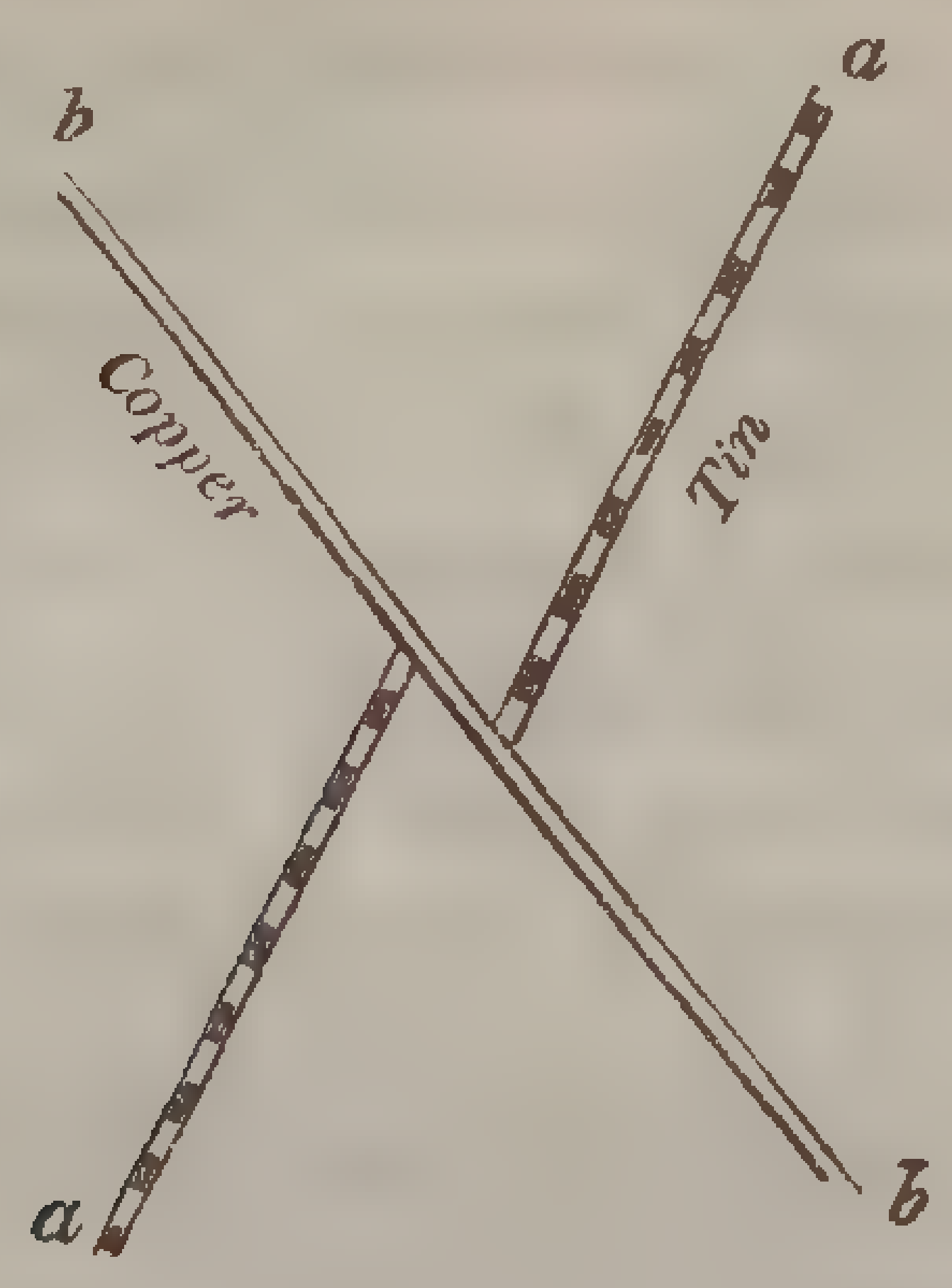


Fig. 711.

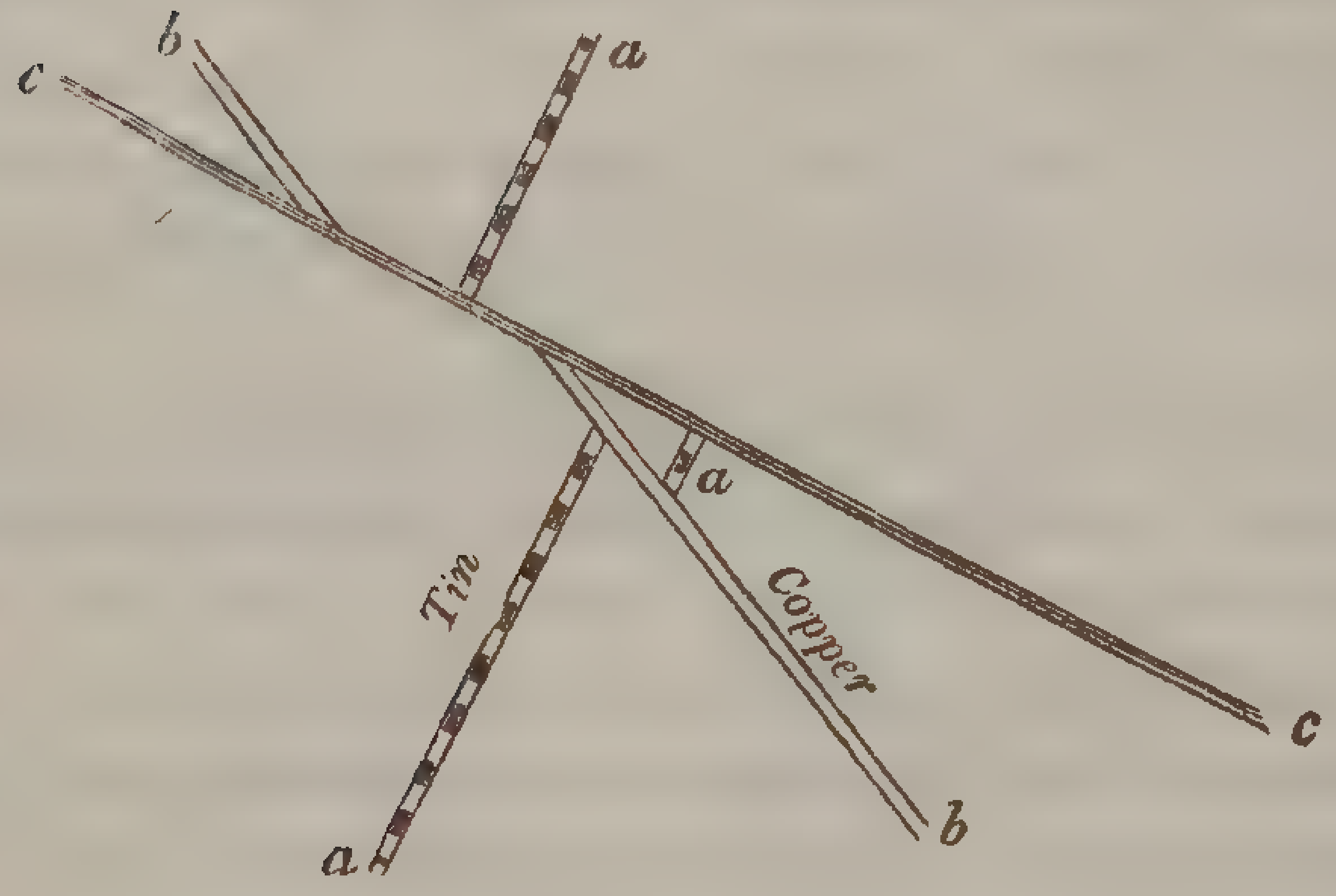
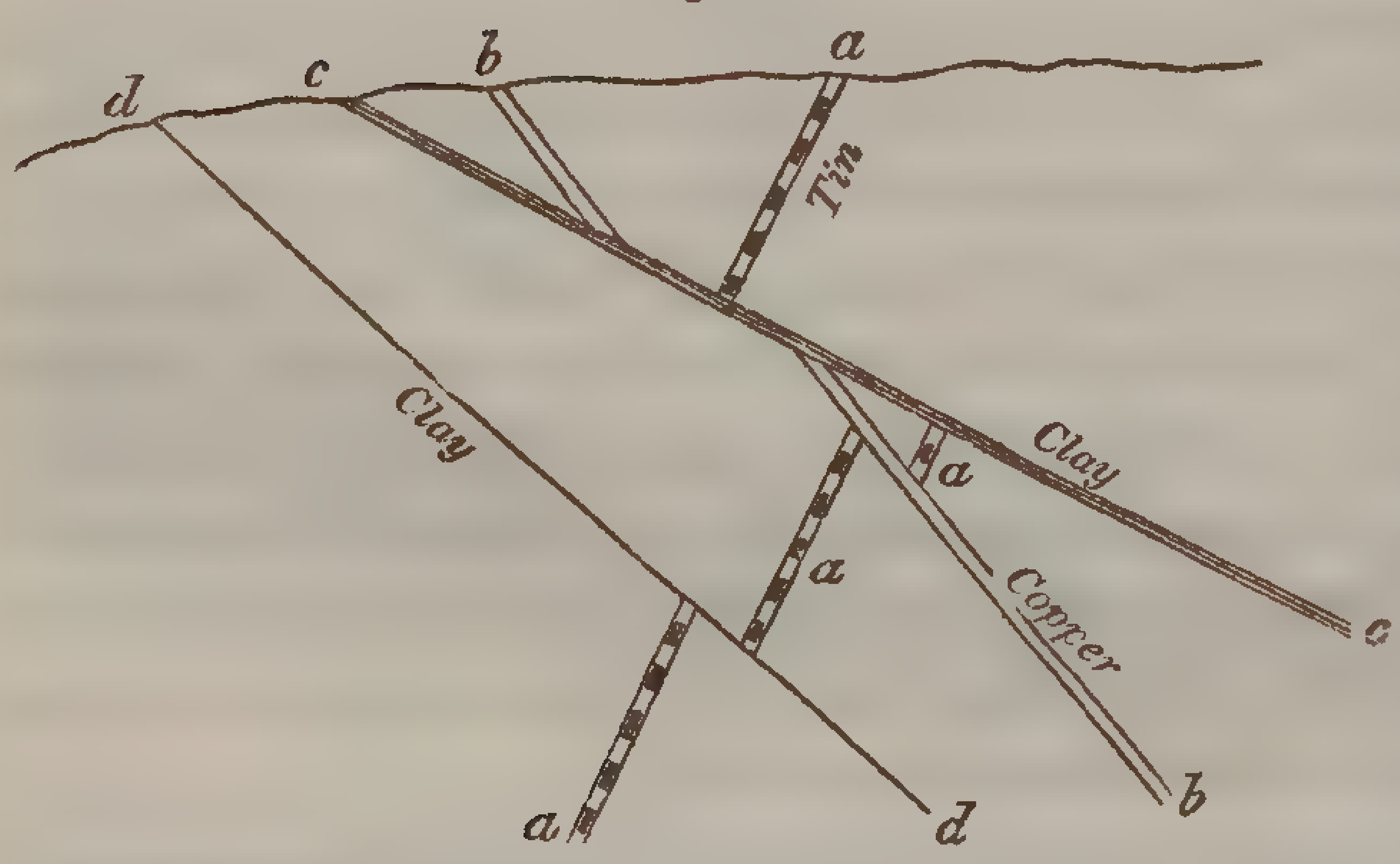


Fig. 712.



Vertical sections of the mine of Huel Peever, Redruth, Cornwall.

The first fissure (*a a*) has been filled with various materials, partly of chemical origin, such as quartz, fluor-spar, peroxide of tin, sulphuret of copper, arsenical pyrites, bismuth, and sulphuret of nickel, and partly of mechanical origin, comprising clay and angular fragments or detritus of the intersected rocks. The plates of quartz and the ores are, in some places, parallel to the vertical sides or walls of the vein, being divided from each other by alternating layers of clay, or other earthy matter. Occasionally the metallic ores are disseminated in detached masses among the veinstones.

It is clear that, after the gradual introduction of the tin and other substances, the second rent (*b b*) was produced by another fracture accompanied by a displacement of the rocks along the plane of *b b*.

This new opening was then filled with minerals, some of them resembling those in *a a*, as fluor-spar (or fluate of lime) and quartz; others different, the copper being plentiful and the tin wanting or very scarce.

We must next suppose the shock of a third earthquake to occur, breaking asunder all the rocks along the line *c c*, fig. 711.; the fissure, in this instance, being only 6 inches wide, and simply filled with clay, derived, probably, from the friction of the walls of the rent, or partly, perhaps, washed in from above. This new movement has heaved the rock in such a manner as to interrupt the continuity of the copper vein (*b b*), and, at the same time, to shift or heave laterally in the same direction a portion of the tin vein which had not previously been broken.

Again, in fig. 712. we see evidence of a fourth fissure (*d d*), also filled with clay, which has cut through the tin vein (*a a*), and has lifted it slightly upwards towards the south. The various changes here represented are not ideal, but are exhibited in a section obtained in working an old Cornish mine, long since abandoned, in the parish of Redruth, called Huel Peever, and described both by Mr. Williams and Mr. Carne.* The principal movement here referred to, or that of *c c*, fig. 712., extends through a space of no less than 84 feet; but in this, as in the case of the other three, it will be seen that the outline of the country above, *d*, *c*, *b*, *a*, &c., or the geographical features of Cornwall, are not affected by any of the dislocations, a powerful denuding force having clearly been exerted subsequently to all the faults. (See above, p. 69.) It is commonly said in Cornwall, that there are eight distinct systems of veins which can in like manner be referred to as many successive movements or fractures; and the German miners of the Hartz Mountains speak also of eight systems of veins, referable to as many periods.

Besides the proofs of mechanical action already explained, the opposite walls of veins are often beautifully polished, as if glazed, and are not unfrequently striated or scored with parallel furrows and ridges, such as would be produced by the continued rubbing together of surfaces of unequal hardness. These smoothed surfaces resemble the rocky floor over which a glacier has passed (see fig. p. 128). They are common even in cases where there has been no shift, and occur equally in non-metalliferous fissures. They are called by miners "slicken-sides," from the German *schlichten*, to plane, and *seite*, side. It is supposed that the lines of the striæ indicate the direction in which the rocks were moved. During one of the minor earthquakes in Chili, which happened about the year 1840, and was described to me by an eye-witness, the brick walls of a building were rent vertically in several places, and made to vibrate for several minutes during each shock, after which they remained uninjured, and without any opening, although the line of each crack was still visible. When all movement had ceased, there were seen on the

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* Geol. Trans. vol. iv. p. 139.; Trans. Roy. Geol. Society, Cornwall, vol. ii. p. 90.

floor of the house, at the bottom of each rent, small heaps of fine brickdust, evidently produced by trituration.

In some of the veins in the mountain limestone of Derbyshire, containing lead, the vein-stuff, which is nearly compact, is occasionally traversed by what may be called a vertical crack passing down the middle of the vein. The two faces in contact are slicken-sides, well polished and fluted, and sometimes covered by a thin coating of lead-ore. When one side of the vein-stuff is removed, the other side cracks, especially if small holes be made in it, and fragments fly off with loud explosions, and continue to do so for some days. The miner, availing himself of this circumstance, makes with his pick small holes about 6 inches apart, and 4 inches deep, and on his return in a few hours finds every part ready broken to his hand.* These phenomena and their causes (probably connected with electrical action) seem scarcely to have attracted the notice which they deserve.

That a great many veins communicated originally with the surface of the country above, or with the bed of the sea, is proved by the occurrence in them of well-rounded pebbles, agreeing with those in superficial alluviums, as in Auvergne and Saxony. In Bohemia, such pebbles have been met with at the depth of 180 fathoms. In Cornwall, Mr. Carne mentions true pebbles of quartz and slate in a tin lode of the Relistran Mine, at the depth of 600 feet below the surface. They were cemented by oxide of tin and bisulphuret of copper, and were traced over a space more than 12 feet long and as many wide.† Marine fossil shells, also, have been found at great depths, having probably been engulphed during submarine earthquakes. Thus, a gryphæa is stated by M. Virlet to have been met with in a lead-mine near Sémur, in France, and a madrepore in a compact vein of cinnabar in Hungary.‡

When different sets or systems of veins occur in the same country, those which are supposed to be of contemporaneous origin, and which are filled with the same kind of metals, often maintain a general parallelism of direction. Thus, for example, both the tin and copper veins in Cornwall run nearly east and west, while the lead-veins run north and south; but there is no general law of direction common to different mining districts. The parallelism of the veins is another reason for regarding them as ordinary fissures, for we observe that contemporaneous trap dikes, admitted by all to be masses of melted matter which have filled rents, are often parallel. Assuming, then, that veins are simply fissures in which chemical and mechanical deposits have accumulated, we may next consider the proofs of their having been filled gradually and often during successive enlargements. I have already spoken of parallel layers of clay, quartz, and ore. Werner himself observed, in a vein near Gersdorff, in Saxony, no less than thirteen beds of different minerals, arranged with the utmost regularity on each side of the central layer. This layer was

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* Conyb. and Phil. Geol. p. 401.; and Farey's Derbysh. p. 243.

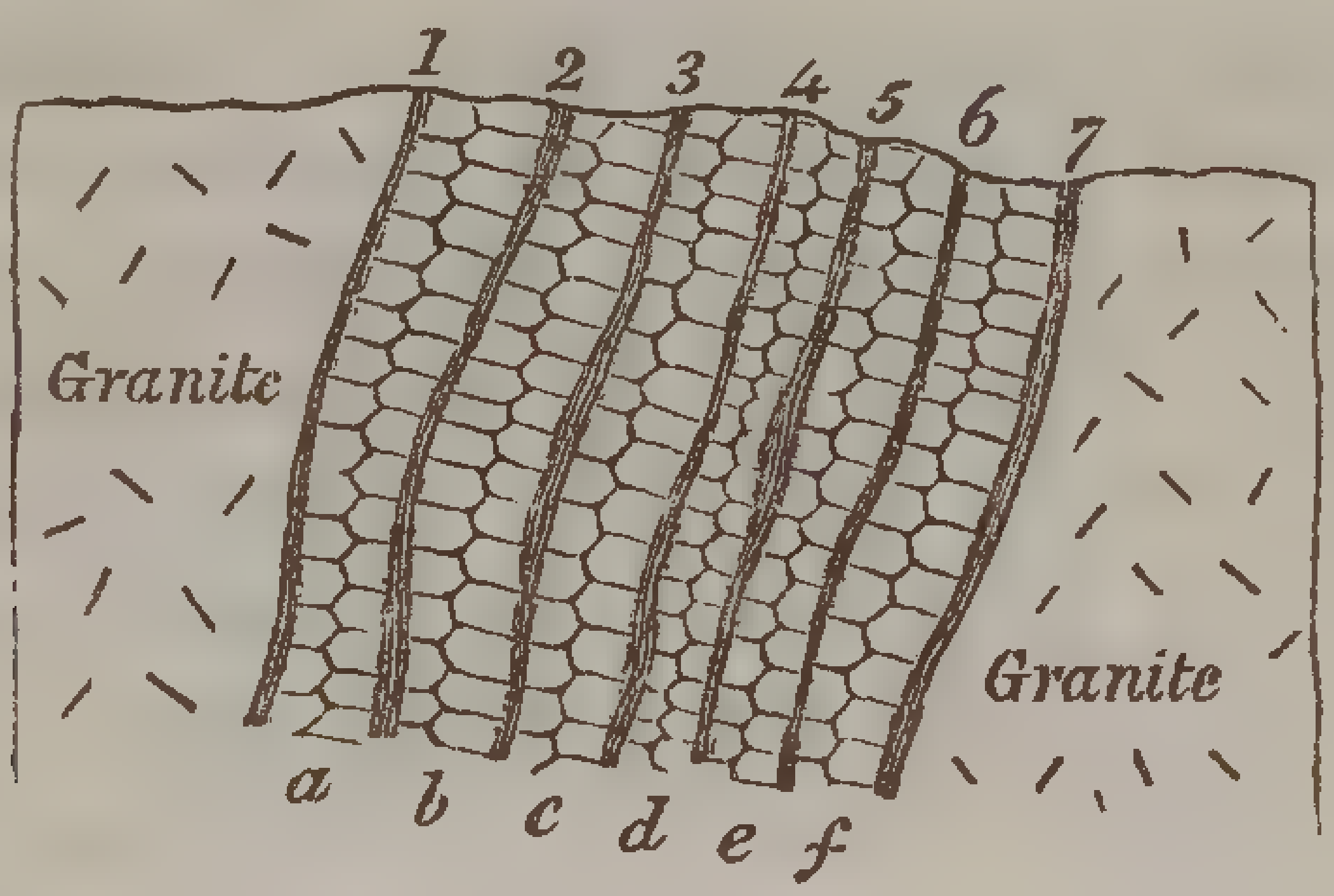
† Carne, Trans. of Geol. Soc. Cornwall, vol. iii. p. 238.

‡ Fournet, Études sur les Dépôts Métallifères.

formed of two beds of calcareous spar, which had evidently lined the opposite walls of a vertical cavity. The thirteen beds followed each other in corresponding order, consisting of fluor-spar, heavy spar, galena, &c. In these cases, the central mass has been last formed, and the two plates which coat the outer walls of the rent on each side are the oldest of all. If they consist of crystalline precipitates, they may be explained by supposing the fissure to have remained unaltered in its dimensions, while a series of changes occurred in the nature of the solutions which rose up from below; but such a mode of deposition, in the case of many successive and parallel layers, appears to be exceptional.

If a veinstone consist of crystalline matter, the points of the crystals are always turned inwards, or towards the centre of the vein; in other words, they point in that direction where there was most space for the development of the crystals. Thus each new layer receives the impression of the crystals of the preceding layer, and imprints its crystals on the one which follows, until at length the whole of the vein is filled: the two layers which meet dovetail the points of their crystals the one into the other. But in Cornwall, some lodes occur where the vertical plates, or *combs*, as they are there called, exhibit crystals so dovetailed as to prove that the same fissure has been often enlarged. Sir H. De la Beche gives the following curious and instructive example (fig. 713.) from a copper-mine in granite, near Redruth.* Each of the plates or combs (*a*, *b*, *c*, *d*, *e*, *f*) are double, having the points of their crystals turned inwards along the axis of the comb. The sides or walls (2, 3, 4, 5, and 6) are parted by a thin covering of ochreous clay, so that each comb is readily separable from another by a moderate blow of the hammer. The breadth of each represents the whole width of the fissure at six successive periods, and the outer walls of the vein, where the first narrow rent was formed, consisted of the granitic surfaces 1 and 7.

Fig. 713.



Copper lode, near Redruth, enlarged at six successive periods.

A somewhat analogous interpretation is applicable to numbers of other cases, where clay, sand, or angular detritus alternate with ores and veinstones. Thus, we may imagine the sides of a fissure to be encrusted with siliceous matter, as Von Buch observed, in Lancerote, the walls of a volcanic crater formed in 1731 to be traversed by an open rent in which hot vapours had deposited hydrate of

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* Geol. Rep. on Cornwall, p. 340.

silica, the incrustation nearly extending to the middle.* Such a vein may then be filled with clay or sand, and afterwards re-opened, the new rent dividing the argillaceous deposit, and allowing a quantity of rubbish to fall down. Various metals and spars may then be precipitated from aqueous solutions among the interstices of this heterogeneous mass.

That such changes have repeatedly occurred, is demonstrated by occasional cross-veins, implying the oblique fracture of previously formed chemical and mechanical deposits. Thus, for example, M. Fournet, in his description of some mines in Auvergne worked under his superintendence, observes that the granite of that country was first penetrated by veins of granite, and then dislocated, so that open rents crossed both the granite and the granitic veins. Into such openings, quartz, accompanied by sulphurets of iron and arsenical pyrites, was introduced. Another convulsion then burst open the rocks along the old line of fracture, and the first set of deposits were cracked and often shattered, so that the new rent was filled, not only with angular fragments of the adjoining rocks, but with pieces of the older veinstones. Polished and striated surfaces on the sides or in the contents of the vein also attest the reality of these movements. A new period of repose then ensued, during which various sulphurets were introduced, together with hornstone quartz, by which angular fragments of the older quartz before mentioned were cemented into a breccia. This period was followed by other dilatations of the same veins, and other sets of mineral deposits, until, at last, pebbles of the basaltic lavas of Auvergne, derived from superficial alluviums, probably of Miocene or older Pliocene date, were swept into the veins. I have not space to enumerate all the changes minutely detailed by M. Fournet, but they are valuable, both to the miner and geologist, as showing how the supposed signs of violent catastrophes may be the monuments, not of one paroxysmal shock, but of reiterated movements.

Such repeated enlargement and re-opening of veins might have been anticipated, if we adopt the theory of fissures, and reflect how few of them have ever been sealed up entirely, and that a country with fissures only partially filled must naturally offer much feebler resistance along the old lines of fracture than anywhere else. It is quite otherwise in the case of dikes, where each opening has been the receptacle of one continuous and homogeneous mass of melted matter, the consolidation of which has taken place under considerable pressure. Trappean dikes can rarely fail to strengthen the rocks at the points where before they were weakest; and if the upheaving force is again exerted in the same direction, the crust of the earth will give way anywhere rather than at the precise points where the first rents were produced.

A large proportion of metalliferous veins have their opposite walls nearly parallel, and sometimes over a wide extent of country. There

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* Principles, ch. xxvii. 8th ed. p. 422.

is a fine example of this in the celebrated vein of Andreasburg in the Hartz, which has been worked for a depth of 500 yards perpendicularly, and 200 horizontally, retaining almost every where a width of 3 feet. But many lodes in Cornwall and elsewhere are extremely variable in size, being 1 or 2 inches in one part, and then 8 or 10 feet in another, at the distance of a few fathoms, and then again narrowing as before. Such alternate swelling and contraction is so often characteristic as to require explanation. The walls of fissures in general, observes Sir H. De la Beche, are rarely perfect planes throughout their entire course, nor could we well expect them to be so, since they commonly pass through rocks of unequal hardness and different mineral composition. If, therefore, the opposite sides of such irregular fissures slide upon each other, that is to say, if there be a fault, as in the case of so many mineral veins, the parallelism of the opposite walls is at once entirely destroyed, as will be readily seen by studying the annexed diagrams.

Fig. 714.

Fig. 715.

Fig. 716.

Let *a b*, fig. 714., be a line of fracture traversing a rock, and let *a b*, fig. 715., represent the same line. Now, if we cut a piece of paper representing this line, and then move the lower portion of this cut paper sideways from *a* to *a'*, taking care that the two pieces of paper still touch each other at the points 1, 2, 3, 4, 5, we obtain an irregular aperture at *c*, and isolated cavities at *d d d*, and when we compare such figures with nature we find that, with certain modifications, they represent the interior of faults and mineral veins. If, instead of sliding the cut paper to the right hand, we move the lower part towards the left, about the same distance that it was previously slid to the right, we obtain considerable variation in the cavities so produced, two long irregular open spaces, *f f*, fig. 716., being then formed. This will serve to show to what slight circumstances considerable variations in the character of the openings between unevenly fractured surfaces may be due, such surfaces being moved upon each other, so as to have numerous points of contact.

Most lodes are perpendicular to the horizon, or nearly so; but some of them have a considerable inclination or "hade," as it is termed, the angles of dip varying from 15° to 45°. The course of a vein is frequently very straight; but if tortuous, it is found to be choked up with clay, stones, and pebbles, at points where it departs most widely from verticality. Hence at places, such as *a*,

Fig. 717.

fig. 717., the miner complains that the ores are "nipped," or greatly reduced in quantity, the space for their free deposition having been interfered with in consequence of the pre-occupancy of the lode by earthy materials. When lodes are many fathoms wide, they are usually filled for the most part with earthy matter, and fragments of rock, through which the ores are much disseminated. The metallic substances frequently coat or encircle detached pieces of rock, which our miners call "horses" or "riders." That we should find some mineral veins which split into branches is also natural, for we observe the same in regard to open fissures.

Chemical deposits in veins.—If we now turn from the mechanical to the chemical agencies which have been instrumental in the production of mineral veins, it may be remarked that those parts of fissures which were not choked up with the ruins of fractured rocks must always have been filled with water; and almost every vein has probably been the channel by which hot springs, so common in countries of volcanos and earthquakes, have made their way to the surface. For we know that the rents in which ores abound extend downwards to vast depths, where the temperature of the interior of the earth is more elevated. We also know that mineral veins are most metalliferous near the contact of plutonic and stratified formations, especially where the former send veins into the latter, a circumstance which indicates an original proximity of veins at their inferior extremity to igneous and heated rocks. It is moreover acknowledged that even those mineral and thermal springs which, in the present state of the globe, are far from volcanos, are nevertheless observed to burst out along great lines of upheaval and dislocation of rocks.* It is also ascertained that all the substances with which hot springs are impregnated agree with those discharged in a gaseous form from volcanos. Many of these bodies occur as veinstones; such as silex, carbonate of lime, sulphur, fluor-spar, sulphate of barytes, magnesia, oxide of iron, and others. I may add that, if veins have been filled with gaseous emanations from masses of melted matter, slowly cooling in the subterranean regions, the contraction of such masses as they pass from a plastic to a solid state would, according to the experiments of Deville on granite (a rock which may be taken as a standard), produce a reduction in volume amounting to 10 per cent. The slow crystallization, therefore, of such plutonic rocks supplies us with a force not only capable of rending open the incumbent rocks by causing a failure of support, but also of giving rise to faults whenever one portion of the earth's crust subsides slowly while another contiguous to it happens to rest on a different foundation, so as to remain unmoved.

Although we are led to infer, from the foregoing reasoning, that there has often been an intimate connection between metalliferous

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* See Dr. Daubeny's Volcanos.

veins and hot springs holding mineral matter in solution, yet we must not on that account expect that the contents of hot springs and mineral veins would be identical. On the contrary, M. E. de Beaumont has judiciously observed that we ought to find in veins those substances which, being least soluble, are not discharged by hot springs,—or that class of simple and compound bodies which the thermal waters ascending from below would first precipitate on the walls of a fissure, as soon as their temperature began slightly to diminish. The higher they mount towards the surface, the more will they cool, till they acquire the average temperature of springs, being in that case chiefly charged with the most soluble substances, such as the alkalis, soda and potash. These are not met with in veins, although they enter so largely into the composition of granitic rocks.*

To a certain extent, therefore, the arrangement and distribution of metallic matter in veins may be referred to ordinary chemical action, or to those variations in temperature, which waters holding the ores in solution must undergo, as they rise upwards from great depths in the earth. But there are other phenomena which do not admit of the same simple explanation. Thus, for example, in Derbyshire, veins containing ores of lead, zinc, and copper, but chiefly lead, traverse alternate beds of limestone and greenstone. The ore is plentiful where the walls of the rent consist of limestone, but is reduced to a mere string when they are formed of greenstone, or "toad-stone," as it is called provincially. Not that the original fissure is narrower where the greenstone occurs, but because more of the space is there filled with veinstones, and the waters at such points have not parted so freely with their metallic contents.

"Lodes in Cornwall," says Mr. Robert W. Fox, "are very much influenced in their metallic riches by the nature of the rock which they traverse, and they often change in this respect very suddenly, in passing from one rock to another. Thus many lodes which yield abundance of ore in granite, are unproductive in clay-slate, or killas, and *vice versâ.* The same observation applies to killas and the granitic porphyry called elvan. Sometimes, in the same continuous vein, the granite will contain copper, and the killas tin, or *vice versâ.*"† Mr. Fox, after ascertaining the existence at present of electric currents in some of the metalliferous veins in Cornwall, has speculated on the probability of the same cause having acted originally on the sulphurets and muriates of copper, tin, iron, and zinc, dissolved in the hot water of fissures, so as to determine the peculiar mode of their distribution. After instituting experiments on this subject, he even endeavoured to account for the prevalence of an east and west direction in the principal Cornish lodes by their position at right angles to the earth's magnetism; but Mr. Henwood and other experienced miners have pointed out objections to the theory; and it must be owned that the direction of veins in different

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* Bulletin, iv. p. 1278.

† R. W. Fox on Mineral Veins, p. 10.

mining districts varies so entirely that it seems to depend on lines of fracture, rather than on the laws of voltaic electricity. Nevertheless, as different kinds of rock would be often in different electrical conditions, we may readily believe that electricity must often govern the arrangement of metallic precipitates in a rent.

"I have observed," says Mr. R. Fox, "that when the chloride of tin in solution is placed in the voltaic circuit, part of the tin is deposited in a metallic state at the negative pole, and part at the positive one, in the state of a peroxide, such as it occurs in our Cornish mines. This experiment may serve to explain why tin is found contiguous to, and intermixed with, copper ore, and likewise separated from it, in other parts of the same lode." *

Relative age of the different metals.—After duly reflecting on the facts above described, we cannot doubt that mineral veins, like eruptions of granite or trap, are referable to many distinct periods of the earth's history, although it may be more difficult to determine the precise age of veins; because they have often remained open for ages, and because, as we have seen, the same fissure, after having been once filled, has frequently been re-opened or enlarged. But besides this diversity of age, it has been supposed by some geologists that certain metals have been produced exclusively in earlier, others in more modern times,—that tin, for example, is of higher antiquity than copper, copper than lead or silver, and all of them more ancient than gold. I shall first point out that the facts once relied upon in support of some of these views are contradicted by later experience, and then consider how far any chronological order of arrangement can be recognised in the position of the precious and other metals in the earth's crust.

In the first place, it is not true that veins in which tin abounds are the oldest lodes worked in Great Britain. The government survey of Ireland has demonstrated, that in Wexford veins of copper and lead (the latter as usual being argentiferous) are much older than the tin of Cornwall. In each of the two countries a very similar series of geological changes has occurred at two distinct epochs,—in Wexford, before the Devonian strata were deposited; in Cornwall, after the carboniferous epoch. To begin with the Irish mining district: We have granite in Wexford, traversed by granite veins, which veins also intrude themselves into the Silurian strata, the same Silurian rocks as well as the veins having been denuded before the Devonian beds were superimposed. Next we find, in the same county, that elvans, or straight dikes of porphyritic granite, have cut through the granite and the veins before mentioned, but have not penetrated the Devonian rocks. Subsequently to these elvans, veins of copper and lead were produced, being of a date certainly posterior to the Silurian, and anterior to the Devonian; for they do not enter the latter, and, what is still more decisive, streaks or layers of derivative copper have been found near Wexford in the

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* R. W. Fox on Mineral Veins, p. 38.

Devonian, not far from points where mines of copper are worked in the Silurian strata.*

Although the precise age of such copper lodes cannot be defined, we may safely affirm that they were either filled at the close of the Silurian or commencement of the Devonian period. Besides copper, lead, and silver, there is some gold in these ancient or primary metalliferous veins. A few fragments also of tin found in Wicklow in the drift are supposed to have been derived from veins of the same age.†

Next, if we turn to Cornwall, we find there also the monuments of a very analogous sequence of events. First the granite was formed; then, about the same period, veins of fine-grained granite, often tortuous (see fig. 692., p. 574.), penetrating both the outer crust of granite and the adjoining fossiliferous or primary rocks, including the coal-measures; thirdly, elvans, holding their course straight through granite, granitic veins, and fossiliferous slates; fourthly, veins of tin also containing copper, the first of those eight systems of fissures of different ages already alluded to, p. 629. Here, then, the tin lodes are newer than the elvans. It has indeed been stated by some Cornish miners that the elvans are in some few instances posterior to the oldest tin-bearing lodes, but the observations of Sir H. de la Beche during the survey led him to an opposite conclusion, and he has shown how the cases referred to in corroboration can be otherwise interpreted.‡ We may, therefore, assert that the most ancient Cornish lodes are younger than the coal-measures of that part of England, and it follows that they are of a much later date than the Irish copper and lead of Wexford and some adjoining counties. How much later, it is not so easy to declare, although probably they are not newer than the beginning of the Permian period, as no tin lodes have been discovered in any red sandstone of the Poikilitic group, which overlies the coal in the south-west of England.

There are lead veins in the Mendip hills which extend through the mountain limestone into the Permian or Dolomitic conglomerate, and others in Glamorganshire which enter the lias. Those worked near Frome, in Somersetshire, have been traced into the Inferior Oolite. In Bohemia, the rich veins of silver of Joachimsthal cut through basalt containing olivine, which overlies tertiary lignite, in which are leaves of dicotyledonous trees. This silver, therefore, is decidedly a tertiary formation. In regard to the age of the gold of the Ural Mountains, in Russia, which, like that of California, is obtained chiefly from auriferous alluvium, it occurs in veins of quartz in the schistose and granitic rocks of that chain, and is supposed by MM. Murchison, De Verneuil, and Keyserling to be newer than the syenitic granite of the Ural—perhaps of tertiary date. They ob-

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* I am indebted to Sir H. De la Beche for this information. See also maps and sections of Irish Survey.

† Sir H. De la Beche, MS. notes on Irish Survey.

‡ Report on Geology of Cornwall, p. 310.

serve, that no gold has yet been found in the Permian conglomerates which lie at the base of the Ural Mountains, although large quantities of iron and copper detritus are mixed with the pebbles of those Permian strata. Hence it seems that the Uralian quartz veins, containing gold and platinum, were not formed or certainly not exposed to aqueous denudation during the Permian era.

In the auriferous alluvium of Russia, California, and Australia, the bones of extinct land-quadrupeds have been met with, those of the mammoth being common in the gravel at the foot of the Ural Mountains, while in Australia they consist of huge marsupials, some of them of the size of the rhinoceros and allied to the living wombat. They belong to the genera Diprotodon and Nototherium of Professor Owen. The gold of Northern Chili is associated in the mines of Los Hornos with copper pyrites, in veins traversing the cretaceo-oolitic formations, so called because its fossils have the character partly of the cretaceous and partly of the oolitic fauna of Europe.* The gold found in the United States, in the mountainous parts of Virginia, North and South Carolina, and Georgia occurs in metamorphic Silurian strata, as well as in auriferous gravel derived from the same.

Gold has now been detected in almost every kind of rock, in slate, quartzite, sandstone, limestone, granite, and serpentine, both in veins and in the rocks themselves at short distances from the veins. In Australia it has been worked successfully not only in alluvium, but in veinstones in the native rock, generally consisting of Silurian shales and slates. It has been traced on that continent, over more than nine degrees of latitude (between the parallels of the 30° and 39° S.), and over twelve of longitude, and yields already an annual supply equal, if not superior, to that of California; nor is there any apparent prospect of this supply diminishing, still less of the exhaustion of the gold fields. It seems reasonable, therefore, to share the anticipations of M. Delesse that the time will come, and cannot be very remote, when a marked depreciation will be experienced in the value of this metal.†

It has been remarked by M. de Beaumont, that lead and some other metals are found in dikes of basalt and greenstone, as well as in mineral veins connected with trap rocks, whereas tin is met with in granite and in veins associated with the granitic series. If this rule hold true generally, the geological position of tin in localities accessible to the miners will belong, for the most part, to rocks older than those bearing lead. The tin veins will be of higher relative antiquity for the same reason that the "underlying" igneous formations or granites which are visible to man are older, on the whole, than the overlying or trappean formations.

If different sets of fissures, originating simultaneously at different levels in the earth's crust, and communicating, some of them with volcanic, others with heated plutonic masses, be filled with different

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* Darwin's S. America, p. 209., &c.

† Annales des Mines, 1853, tom. iii. p. 185.

metals, it will follow that those formed farthest from the surface will usually require the longest time before they can be exposed superficially. In order to bring them into view, or within reach of the miner, a greater amount of upheaval and denudation must take place in proportion as they have lain deeper when first moved. A considerable series of geological revolutions must intervene before any part of the fissure, which has been for ages in the proximity of the plutonic rocks, so as to receive the gases discharged from it when it was cooling, can emerge into the atmosphere. But I need not enlarge on this subject, as the reader will remember what was said in the 30th, 34th, and 37th chapters, on the chronology of the volcanic and hypogene formations.

Concluding Remarks.—The theory of the origin of the hypogene rocks, at a variety of successive periods, as expounded in two of the chapters just cited, and still more the doctrine that such rocks may be now in the daily course of formation, has made and still makes its way, but slowly, into favour. The disinclination to embrace it has arisen partly from an inherent obscurity in the very nature of the evidence of plutonic action when developed on a great scale, at particular periods. It has also sprung, in some degree, from extrinsic considerations; many geologists having been unwilling to believe the doctrine of transmutation of fossiliferous into crystalline rocks, because they were desirous of finding proofs of a beginning, and of tracing back the history of our terraqueous system to times anterior to the creation of organic beings. But if these expectations have been disappointed, if we have found it impossible to assign a limit to that time throughout which it has pleased an Omnipotent and Eternal Being to manifest his creative power, we have at least succeeded beyond all hope in carrying back our researches to times antecedent to the existence of man. We can prove that man had a beginning, and that, all the species now contemporary with man, and many others which preceded, had also a beginning, and that, consequently, the present state of the organic world has not gone on from all eternity, as some philosophers have maintained.

It can be shown that the earth's surface has been remodelled again and again; mountain chains have been raised or sunk; valleys formed, filled up, and then re-excavated; sea and land have changed places; yet throughout all these revolutions, and the consequent alterations of local and general climate, animal and vegetable life has been sustained. This has been accomplished without violation of the laws now governing the organic creation, by which limits are assigned to the variability of species. The succession of living beings appears to have been continued not by the transmutation of species, but by the introduction into the earth from time to time of new plants and animals, and each assemblage of new species must have been admirably fitted for the new states of the globe as they arose, or they would not have increased and multiplied and endured for indefinite periods.*

Astronomy has been unable to establish the plurality of habitable worlds throughout space, however favourite a subject of conjecture and speculation; but geology, although it cannot prove that other planets are peopled with appropriate races of living beings, has demonstrated the truth of conclusions scarcely less wonderful,—the existence on our own planet of so many habitable surfaces, or worlds as they have been called, each distinct in time, and peopled with its peculiar races of aquatic and terrestrial beings.

The proofs now accumulated of the close analogy between extinct and recent species are such as to leave no doubt on the mind that the same harmony of parts and beauty of contrivance which we admire in the living creation has equally characterized the organic world at remote periods. Thus as we increase our knowledge of the inexhaustible variety displayed in living nature, and admire the infinite wisdom and power which it displays, our admiration is multiplied by the reflection, that it is only the last of a great series of preexisting creations, of which we cannot estimate the number or limit in times past.†

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* See Principles of Geol., Book 3.

† See the author's Anniv. Address to the Geol. Soc. 1837. Proceedings G S. vol. ii. p. 520.

INDEX.

[*The Fossils, the names of which are printed in Italics, are figures in the volume.*]

THE END.

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