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I.—*On some of the Microscopical Objects found in the Mud of the Levant, and other Deposits; with Remarks on the mode of formation of Calcareous and Infusorial Siliceous Rocks.* By W. C. WILLIAMSON, Esq.

Communicated by J. P. JOULE, Esq. (Read November 4, 1845.)*

HAVING received from my two friends, Mr. Wm. Reckitt, of Boston, and Mr. Sidebotham, of Manchester, specimens of the friable calcareous deposit which is now accumulating under the waters of the Levant,† I have resolved, after a

* Some additional matter has been incorporated since the Paper was read.

† The term Levant, "is applied not only to the shores, but the seas, over which the sun rises to the morning-ward of Malta." The Crescent and the Cross, by Elias Warburton, Esq. Vol. ii. p. 1.

careful examination of them under the microscope, to offer the results of my observations to the Society, believing that the subject will be interesting to the members on two accounts. In the first place, because the deposit furnishes an admirable illustration of the agencies, by which many of the more ancient calcareous rocks have been formed; and in the second, because the microscopic organisms with which it abounds, exhibit beautiful examples of some of those lower tribes of plants and animals, which are now attracting general attention, but many of which have not yet been brought before this society.

Various speculations have been advanced to account for the origin of cretaceous and limestone strata. Of these, time will not allow me to dwell upon more than the two or three which have been the most popular.

The first is the hypothesis, which supposed, that calcareous rocks have been formed by the accumulation of the comminuted portions of shells and corals, previously broken up by the mechanical movements of the ocean; a view, which was entertained by Linnæus in 1745, and again by Buffon in 1749, and which has been more recently revived by Mr. M'Culloch,* though in a somewhat untenable form. This hypothesis was considered to be open to several objections,—especially when applied to such strata as the Chalk. One was, that such an accumulation of broken shells and corals, could scarcely be conceived to consist of particles so minute and uniform as those of the Chalk. Another, that any mechanical action, as that of water, equal to the production of such a degree of comminution, would also have destroyed the sharp outlines of the imbedded fossils. The same difficulties existed with reference to many of the older limestones, but less so to some of the coarse deposits of the Oolitic Era.

Analogous to this was the supposition that many limestone strata had been vast coral reefs, enclosing and alternating with calcareous sediments, produced by the abrasion of shells and corals by the waves.† Though partly applicable to some of the beds of the Coralline Oolite of Yorkshire, yet this hypothesis when applied to

* M'Culloch's System of Geology. Vol. i. p. 219.

† Lyell's Elements of Geology. p. 220. Many illustrative facts are also recorded in the third edition of his Principles of Geology. Vol. iii. p. 234, et seq.

limestones on an extended scale, was open to the same objections as the preceding one.

These explanations not being considered satisfactory, another view was propounded, and received by many as sufficient to account for most of the phenomena presented by calcareous rocks. It was supposed that the waters of the ocean contained large quantities of lime in solution, and that in the deeper seas, where undisturbed by local currents produced along the coasts, a slow chemical decomposition took place, causing the precipitation of an insoluble carbonate of lime.* To account for the existence of lime in the sea, submarine volcanoes and volcanic springs were had recourse to; it being supposed, not without reason, that such springs did from time to time discharge large quantities of calcareous matter into the ocean.†

Faint glimpses of another hypothesis had been obtained by a few authors. Early in the eighteenth century, Soldani had collected, from less than an ounce and a half of stone from the hills of

* Encyclopædia Metropolitana. Article, Geology. pp. 544 and 656.

† Lyell's Principles of Geology. Vol. iii. p. 240.

Casciana, in Tuscany, 10,454 microscopic chambered shells, and had observed that the rest of the stone was composed of fragments of shells, of minute spines of Echini, and of a sparry calcareous matter. He was also aware that analogous microscopic organisms existed in vast abundance in the waters of the Mediterranean.* Lamarck had subsequently observed the abundance of minute, but perfect Foraminifera in the strata in the neighbourhood of Paris, and remarked "that the remains of such minute animals have added much more to the mass of materials which compose the crust of the globe, than the bones of hippopotami, elephants, and whales."† The Abbé Alberto Fortis, Targioni Tozzetti, and other observers, had likewise noticed the existence of strata composed entirely of accumulated Nummulites.‡

Such was the imperfect state of things when, in 1835, Professor Ehrenberg startled the scientific world by the announcement, that there were in existence rocks composed wholly and entirely of the fossil remains of animals so minute, that

* Lyell's Principles of Geology. Vol. i. p. 77.

† Buckland's Bridgewater Treatise. p. 388.

‡ Parkinson's Organic Remains. pp. 156 to 158.

40,000,000 would only occupy the space of a cubic inch; and in 1838 he stated to the Royal Academy of Sciences of Berlin, that the common white Chalk, in many localities, contained vast numbers of siliceous Infusoria, of five or six species, as well as Polythalamia,—microscopic chambered shells, then generally considered to be minute Cephalopoda. In 1837 our countryman, Mr. Lonsdale, found that the English Chalk contained many of these microscopic Polythalamia.* Similar forms were also detected by the above observers, and by the Rev. J. B. Reade, in flints and analogous siliceous structures.† These facts led many to the conclusion, that Chalk and Chalk flints, if not all calcareous deposits, had been formed, not so much by the broken atoms of the larger organisms, as by the accumulated remains of siliceous Infusoria and calcareous Foraminifera. This view seems to be held by Ehrenberg, who, to account for the presence of what appear to be inorganic atoms, remarks, that "The minute inorganic calcareous particles, produced by the disintegration of the microscopic organisms, are united by a peculiar crystalloid process, which

* Lyell's Principles of Geology, p. 56.

† Annals of Natural History. Vol. xi. p. 194.

may be compared to crystallization, but is of a coarser nature, and essentially different from it."*

Thus we are manifestly approximating to the early conceptions of Linnæus and Buffon, who, if the above views are correct, were not far in error in the general principle which they advocated, viz., the organic origin of limestone rocks,—though they were completely in the dark as to the facts by which the correctness of their hypothesis was to be ultimately tested and proved.

In most geological questions, we are only safe in our generalizations, so long as we test our explanation of the phenomena presented in the crust of the globe, by the effects of active agencies now operating upon its surface. Fuschel laid the foundation of a glorious truth when he declared, that "the earth has always presented phenomena similar to those of the present day."† It is a vital error to regard the world as having been the theatre of agencies which have long since ceased to act. Overwhelmed by the evidences of mighty forces and indefinite periods, we are in danger of forgetting

* Observations on the Organic Composition of Chalk and Chalk Marl.—Mag. Natural History, 1841, p. 305.

† Delabeches's Geol. Manual, p. 193.

that nature is, on the whole, unchanged in the general choice of her instruments, as well as of the laws which regulate their operations; and that, consequently, if we would hope to penetrate the mysterious labyrinth in which she has left many of her ancient secrets concealed, we must commence with the existing exhibitions of nature at work, and trace backward the winding paths by which she has advanced. She is still labouring as of old; and Mr. Lyell has done geologists a noble service in impressing on their minds the extent and power of the forces she has still at her command. By thus diligently enquiring what she is doing, and can do, we may arrive at a comprehension of what she has done, and of the way in which it has been accomplished.

These views apply especially to the *quæstio vexata* of the origin of calcareous strata, many of which have undergone such chemical changes since they were deposited, as have rendered the records of their early history obscure. An extensive metamorphism has changed their appearance, —characters, once clear and legible, are now like those of a time-worn manuscript, difficult to decipher. But in recent calcareous deposits, like that of the Levant, we are able to investigate a portion of this problem under advantageous circumstances. The sedimentary accumulation is now going on. The organisms which constitute it, are unaltered in their structure; and indeed, many of them still contain green animal matter, shewing them to have been living when they were collected. They have been subjected to none of the changes produced by long-continued chemical action, or mechanical pressure; and, consequently, in this example we may form some estimate of how much is owing respectively to organic and inorganic causes.

It has long been known to geologists that in both the Adriatic and the Mediterranean a modern calcareous stratum is in process of formation. On examining several specimens of this sediment, brought me from the Adriatic side of the Levant, under a magnifier having a power of 250 diameters, I found that what, to the unassisted eye, appeared to be a fine powder, mixed with fragments of broken shells, is mainly, if not entirely, an accumulation of organic atoms, of which the greater number are minute and perfect organisms, varying from 1-20th to 1-2000th of an inch in diameter. These consist chiefly of Foraminifera, microscopic Corallines, siliceous Infusoria, spicula of Sponges, and detached frustules, belonging to the interesting group of Diatomaceæ. Another part was composed of the small comminuted fragments of Echinoderms, and some of the larger Molluscs, the latter consisting chiefly of detached and broken prisms of carbonate of lime, such as a very small geological change would convert into what would appear inorganic semi-crystalline atoms. Of truly inorganic fragments, excepting a few sand grains I have seen few or no traces. There are many which I once conceived to be such, but one after another, I have been able to identify them all, and am now led to believe that the whole deposit owes its existence to the steady and continued operation of vital causes. It is not intended to assert, with M'Culloch, that lime is an organic product, but that, so far as portions of the Levant mud are concerned, living organizations have been the sole instruments by which lime and silica have been separated from the water of the seas, and converted into an insoluble form, their constant accumulation causing the existence of a calcareous sediment, which only requires a sufficient length of time, without the interference of any great physical disturbing causes, to produce strata of indefinite thickness.

I will now direct the attention of the Society to the character, and more remarkable forms of these interesting structures.

In the lowest departments of the animal and vegetable worlds, there exist several groups of organisms of doubtful affinities, which have consequently been claimed alike by the botanist and the zoologist. Amongst the most interesting of these are the Diatomaceæ and the Desmideæ. Professor Ehrenberg has figured many of them in his large work on living Infusoria, as animals; for, although he occasionally asks the question, "an animale, an vegetabile?" it is easy to see to which side he inclines. Mr. Dalrymple has also advocated the same view with reference to some of the genera. On the other hand, Kutzing, Agardh, Meneghini, Berkley, Greville, Ralfs, and a host of botanists, have held the opposite opinion, and viewed them as early forms of vegetable life. With reference to the Desmideæ*

* Though the Desmideæ have less connexion with the object of this paper than the Diatomaceæ, the question of their nature is not altogether alien. Some of the beautiful stellate and hirsute spores of Staurastrum, and allied genera, bear so close a resemblance to the fossil Xanthidia that some naturalists are convinced of their identity. I possess spores

there is little doubt but that the botanists are right. The advocates of their animal nature have laid great stress upon their (supposed) powers of locomotion; the admission of indigo into their interior; their increase by self-division; the contractility of their lining membrane on the application of certain reagents; and on the assumed absence of starch from their interior.

None of these reasons appear sufficient to establish the point, even did they all exist. Locomotion is certainly not peculiar to the animal kingdom: the spores of many undoubted Confervæ commence their active and restless movements before they leave the cells of the parent plant. After they escape, Mr. Hassal observes, "they fall into the water, through which they speedily begin to move hither and thither; now progressing in a straight line, with the rostra in advance—now wheeling round and pursuing

of Staurastrum mucronatum, collected by my enthusiastic friend Mr. Ralfs, which cannot possibly be distinguished, so far as form is concerned, from many specimens of Xanthidium ramosum, so common in chalk flints. Notwithstanding this, however, my present conviction is, that the Xanthidia will prove to be spores or gemmules of some of the lower animals, —Polypifera or Porifera.

a different course; now letting their rostra drop and oscillating upon them, like balloons ere the strings are cut, or like tops, their centripetal force being nearly expended; now altogether stopping, and anon resuming their curious and eccentric motions. Truly wonderful is the velocity with which these microscopic objects progress, their relative speed far surpassing that of the swiftest race-horse; after a time, however, the motion becomes much retarded, and at length the zoospores then lie as though dead. Not so, however. They have merely lost the power of locomotion. The vital principle is still active within them, and they are seen to expand, to become partitioned, and if the species be of an attached kind, each zoospore will emit from its transparent extremity, two or more radicles, whereby it becomes finally and for ever fixed."* The admission of indigo into the interior of the Desmideæ, is a very unsatisfactory test, even had it been observed to succeed in all cases, which it has not. The increase by spontaneous division is now shown to be exhibited by many of the true Confervæ, of whose vegetability there can be no doubt. Indeed, it is probable that something very

* Hassal's History of British Freshwater Confervæ. Vol. i. page 11.

analogous to division is the basis of the increase of most cell structures, animal as well as vegetable. The contraction of the lining membrane is also observed, according to Mr. Hassal, in many Confervæ. The assumed absence of starch from their interior is shewn by Meyen, Ralfs, and Jenner, to be an error.

On the other hand, there are certain peculiarities of a positive kind which identify them with plants. Of these I will only cite that of conjugation, which connects them by the closest possible analogy, with a large number of true Algæ.

The real nature of the allied group of the Diatomaceæ is a question less easily disposed of. They are objects more or less filamentous, the filaments being divided into joints or frustules, composed of pure transparent silex, and containing in their interior brown colouring matter, and a number of vertical siliceous plates, the visible edges of which often give to the surface of the frustules the most elaborate markings. These joints exhibit a constant tendency towards a partial separation, cohering only by one of their angles. Their reproduction appears analogous in many cases to that of the Desmidiaceæ, being probably by germs or spores, or, as appears to be the case in many species, by the formation of two new siliceous cells, in the interior of the old one, each cell thus becoming the germ of a new and self-increasing organism. There are many reasons for referring these curious and elegant creatures also to the vegetable world; but on the other hand, many points of their history bring them so near to the Coscinodisci, and other supposed siliceous Infusoria, that it appears almost impossible to come to a definite conclusion on the subject.

I have dwelt the longer on these families because of their growing importance to geologists. Most modern geological works contain some allusion to them under the terms Gallionellæ, Baccillariæ, &c.*; but very few doubt for a moment their animal character. The extensive discovery of their siliceous cases amongst tertiary strata, especially by Professors Ehrenberg, Bailey, and Rogers, has given them an important position amongst the organic remains of a former world; and, consequently, it is desirable to bear in mind, in our generalizations, that the question of their real nature is yet *sub judice*.

* Lyell's Elements, p. 52.—Dr. Bailey's valuable Papers in Silliman's American Journal.

Many highly interesting examples of this group occur in the Levant Deposit. The most striking is the *Denticella tridens, Ehr.*—the Zygoceros Tuomeyi of Bailey. (fig. 1.) The figure represents two of the frustules, many of which have probably been joined together, forming an elongated filament. The same species has been found by Dr. Bailey in the siliceous infusorial marls of Piscatoway and Petersburgh, North America.

Biddulphia pulchella (fig. 2.) is another beautiful form belonging to the same group. Two frustules are also represented. It is found on our own coasts. Dr. Ehrenberg has obtained it from what he considered to be the chalk marls of Greece, and also in a recent state in the Baltic, the North Sea, and from the coast of Cuba; Dr. Bailey has detected it at Rockaway, Long Island; and it is contained in a slide of curious objects from one of the Phillipine Islands, for which I am indebted to the same indefatigable observer:—an interesting illustration of the cosmopolite character of some of these organisms.

Amphitetras (fig. 3.) is an analogous genus, of which the end of one frustule is exhibited. One species, the A. antediluviana, occurs on the British

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coasts, but differs from the present form in having its lateral surfaces less concave. It may, however, only be a variety; as many of the Diatomaceæ exhibit considerable variations of form in the same species.

Grammatophora presents at least two species. *G. Africana, Ehr.* (figs. 4.6.—fig. 8. is probably a small variety of the same—*), and G. tæniæformis (fig. 7, and probably fig. 9.) The former of these species occurs on our coasts. I have received it from Mr. Ralfs, who collected it at Ilfracombe; and I have met with it rather abundantly, along with G. tæniæformis, in the stomachs of crabs from the west coast of Scotland. It is one of the most beautiful of this interesting group, and when occurring in long, zigzag chains, the partially separated frustules cohering by the angles, it constitutes an exquisite microscopic

* Mr. Ralfs writes to me, "Kutzing names my Striatella tæniæformis, var γ serpentina, Grammatophora serpentina, with the following synonyms:—Stri. tæniæformis γ serpentina, Ralfs. Grammatophora Africana, Ehr.? so that, probably, it is Ehrenberg's species." Under Grammatophora marina, Kutzing has the following synonyms:—Conf. tæniæformis E. B. Diat. marinum Lyngb. Diat. tæniæformæ, marinum and Lyngbyei, Ag.—Bacillaria Cleopatra and Grammatophora Oceanica, Ehr.

object. I have also seen it in the guano from Ichaboe.

Fig. 5 may be only an elongated variety of Grammatophora Africana. I have received it from Dr. Bailey amongst some objects obtained at Smyrna, where it occurs along with the true G. Africana. I have never seen it on our own coasts, though G. Africana is not uncommon; hence it may possibly be distinct.

Striatella. (fig. 11.) This is apparently a slight variety of the S. arcuata found on our own coasts.

Fragillaria. (fig. 12.) Long chains of frustules occasionally occur. They are analogous to some of the fossil forms called Bacillariæ. The genus is met with in both fresh and salt water.

Gomphonema. (figs. 13, 14.) This is also a marine as well as a fluviatile genus, in which the frustules are generally supported on a long and flexible stem or pedicle. I have observed two species, both different from those which occur on our own coasts. Fig. 13 may possibly be G. geminatum, which it closely resembles. It is a freshwater species; but Mr. Ralfs kindly informs us that he has occasionally found it brought down by the rivers into marine marshes.

Arranged along with the Diatomacæe, by many authors, are the singular group of Naviculaceæ, small siliceous boat-like bodies, whose affinities are even yet more doubtful than those organisms already noticed, containing a peculiar green internal organization; not forming chains like most of the preceding genera, but each being independent; possessing great powers of locomotion; manifesting all the phenomena of fissiparous generation, and exhibiting, when treated with iodine, well-marked traces of the existence of the vegetable product starch; connected with the preceding group by the genus Cocconema, in which, as in Gomphonema, the siliceous frustules contain a granular endochrome, and are supported on long flexible pedicles; and yet, when detached, the frustules being distinguishable by any known character from true Navicula! Altogether, we are involved in a labyrinth of difficulties, from which we cannot easily extricate ourselves.

Ehrenberg believes that he has observed in several forms retractile pseudopodia,—organs of progression projected through pores in the siliceous cases. If he be correct, this would seem to identify them with the animal kingdom; but neither have I, nor any of the microscopists with whom I have come in contact, been successful in our search for these pseudopodia.

A great variety of forms belonging to this interesting group occur in the Levant deposits. From these I have selected some of the most remarkable. Figs. 15 to 21 represent various examples of the genus Navicula. Fig. 15 is a beautiful and not uncommon species,—*a* exhibits the anterior and *b* the lateral aspect. Fig. 20 is apparently Ehrenberg's Navicula sigma.

Fig. 22 is an exquisite species of Surirella, allied to S. elegans, *a* representing the front, and *b* one extremity of the shell. Figs. 23 and 24 are two species of Cocconeis, a genus of parasitic forms which occur in the greatest abundance on the English coasts, many of the smaller Algæ being covered with them in the most incredible profusion. Their power of fixing themselves to foreign substances, appears to indicate the existence of something allied to the pseudopodia of Ehrenberg.

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Fig. 25* is a species of Cocconema, separated from its pedicle, which latter character alone seems to distinguish this curious genus from the Naviculæ.

The objects to which I would next direct attention also belong to the disputed domain which appears to link the animal with the vegetable kingdom. They are the spicula of sponges. It has long been known that some sponges have their elastic network strengthened by siliceous and calcareous spicula; but the number of forms with which naturalists were acquainted was very limited, and indeed mainly referable to two types, the acicular and the tri-radiate, the former being long believed to represent the siliceous, and the latter the calcareous structures. Within the last few years, however, the labours of Mr. Bowerbank and others have led to the discovery of many varieties, alike peculiar and beautiful. Several of these occur in the Levant mud, as might have been expected from the known abundance of sponges in the Mediterranean and neighbouring seas.

* The number is accidentally omitted from the figure in the upper corner of Plate II.

Whether the sponge is an animal or a vegetable is as yet an undecided question. Dr. Johnston holds the latter opinion ; whilst Dr. Grant and others, judging from the anomalous movements they communicate to surrounding fluids, so often spoken of as a circulation,* and from the developement and motion of their ciliated germs, contend for their animal nature. The latter, however, have been already shown to be phenomena often observed in the lower departments of the vegetable kingdom. Mr. Bowerbank, after pointing out the existence of spicula in some of the Corallidæ (Anthopora) so closely resembling those of many of the Halichondriæ (fig. 46) as not to be distinguished from them, argues from this and some other analogous facts in favour of their

* This peculiar movement is admitted by all to be a difficulty in the way of their being regarded as vegetables. It is much to be desired that the term "circulation" should cease to be applied to it, as the expression gives an erroneous idea of the nature of the movement, and most probably of its object also ; for to consider sponges as possessing a true circulation and capillary vessels, as is done by some microscopic observers, is to set at defiance all the fundamental truths of physiology —truths not to be assailed except after long observation, and on the clearest possible evidence.

animality.* Mr. Hogg, in his investigation on the action of light as affecting the colour of the river sponge, *Spongilla fluviatilis*,† has advanced good arguments in favour of its being a plant, a conclusion in which most naturalists are now agreed. Dr. Bailey has pointed out the existence of siliceous spicula in unquestionably fresh-water deposits in the state of Maine, U. S., so analogous to those of some marine sponges as to be almost identical;‡ yet they are doubtless those of a fresh-water species. This is supported by Struve's analysis of the Spongilla, in which he found, that the ashes left after combustion contained 94.66 per cent of silica.§ These facts indicate a close affinity between the marine and fresh-water forms, and, consequently, increase the probability that the former are more closely allied to the vegetable than to the animal world. On the other hand, the existence of analogous siliceous spicula in Cliona and Anthopora and calcareous ones in the tissues

* Mr. Bowerbank on the Organic Tissues in the Bony Structure of the Corallidæ. Phil. Trans. Royal Society. 1842. Part I, p. 219.

† Paper read to the Royal Society, June 21, 1838.

‡ Silliman's Journal. Vol. xlvi. p. 307.

§ Records of General Science, 1836. Vol. iii. p. 157.

of many of the Eolidæ,* constitute important links connecting them with the animal kingdom. By what mysterious process the simple textures of the sponges have the power of throwing into such exquisitely beautiful forms the silica obtained from the waters of the ocean, it is impossible to say. The manner in which each species preserves its own, in many instances peculiar, form, indicates that there is some apparatus for effecting the object which has as yet escaped detection. In a number of instances, a species may be identified by its elaborately marked spicula; and in others, where one general type prevails, as in the case of the acicular spiculum amongst the Halichondriæ, the different species often present well marked peculiarities of size and form. Sponge spicula are not equally numerous in all the specimens of Levant sediment that I have examined. In some they are very abundant —in others they are comparatively rare. This was to be expected, as any local causes influencing the growth of living sponges would also affect the distribution of their spicula.

The most common form is the calcareous tri-

* See Alder and Hancock's Monograph on the British Nudibranchiate Mollusca.

radiate (fig. 45.) It occurs in many living species. The siliceous acicular spiculum is also abundant, sometimes with one end thickened like the head of a pin (fig. 47) a form which I have found in the British Halichondria sulphurea (*Bean's MSS*) ; and which also exists in Dr. Grant's sponge-like Zoophyte, Cliona celata ;* at others pointed at each extremity (fig. 46). The latter is the most common siliceous form, and has been found by Mr. Bowerbank in many of the keratose sponges, from which they were believed to be absent, and which were, consequently, made into a separate group. Fig. 46 is not only the common form amongst the Halichondriæ, but has been found by Mr. Bowerbank in Anthopora—one of the Corallidæ.†

Two forms of spicula occur, which, probably, belong to some species of Tetheia. In the fibro-fleshy texture of this sponge there are bundles of spicula which radiate from the centre to the

* Found filling the holes in oyster-shells on the sea coast, near Preston Pans.—Johnston's History of British Zoophytes, p. 305.

† On the Organic Tissues in the Bony Structure of the Corallidæ.—See page 22.

circumference, some of them passing through the thick skin or rind. In the latter are bundles of shorter spicula, and in the interstices between these are sparingly scattered minute stellate siliceous bodies of great beauty, resembling in form the bossed iron balls hung by a chain to the war club used in the early ages. Examples of at least two species (figs. 40, 41) occur in some specimens of the Levant mud, one of them (fig. 40) being rather abundant. Analogous forms have been found by Dr. Bailey in the siliceous Infusorial deposits of Bermuda and Pittsburg. Stellate spicula occur in some species of the genus Grantia and in Mr. Bowerbank's new sponge Pachymatisma Johnstoniana.

I have also found a considerable number of small siliceous balls, which belong to some species of Geodia.* In this, as in Tetheia, we find long radiating spicula, but with the external extremity often divided into three recurved

* Dr. Johnson refers to the Cydonium Mulleri of Fleming, under the head Geodia Zetlandica, including it among the Sponges.—Hist. of British Sponges, p. 195; and again in his History of British Zoophytes, speaking of it as one of the Alcyonidæ. Are these distinct objects?

points, like grappling irons. The skin, or outer crust, is dry, and consists of an aggregation of small siliceous globules, cemented together by an organic mucus, so as to form a solid pavement. Each globule, both in the living species and in those from the Levant, is delicately reticulated. Fig. 42 represents one of the round spicula, and Fig. 43 is probably one of the radiating ones from the same sponge. Fig. 48 represents a form in which the surface is armed with symmetrical rings of minute points. I have observed it in sponges from our English coast, from the Mediterranean and West Indian Seas, and also along with other organisms in the Ichaboe guano. I have occasionally seen an analogous muricated form in which the small points were dispersed irregularly, instead of being arranged in transverse rings.

Fig. 49 is a portion of a very large calcareous spiculum in which the surface is covered with irregularly arranged projections, or flattened papillæ, which preserve, however, a little tendency to a spiral arrangement. I have seen forms somewhat similar in sand from the West Indies. I suspect they belong to some of the Eolidæ so beautifully illustrated by Messrs. Alder and

Hancock, in the work now publishing by the Ray Society.*

Foraminifera.—The most abundant as well as the most striking organisms belonging to the Levant deposit are the Foraminifera, or Polythalamia;—interesting from their individual peculiarities, and important from their geological relations.

Zoologists have long been acquainted with the existence of recent and fossil forms of microscopic chambered shells from almost every European country. Stobæus had arranged the Nummulites amongst the corals,† thus anticipating later discoveries. In 1732 Breyn pointed out the resemblance between many of the forms and the recent Nautilus, which view was also adopted by Gesner. In the same century Soldani had minutely investigated those of the Mediterranean, treading in the steps of Plancus and others who had led the way;‡ and between the years 1789 and 1799 he published his large work on the subject.

* See Goniodoris nodosa—Table 18, fig. 11, and Polycera ocellata—Table 23, fig. 8. Monograph on the British Nudibranchiate Mollusca.

† In Opusculis.

‡ Annales des Sciences Naturelles. 1826. Vol. vii., p. 102.

In 1784 Walker examined those of our own coast—a labour in which he was followed by Montagu, in 1803 and 1808, whilst Fichtel and Moll recorded many additional recent forms ; and subsequently Lamarck especially studied the fossil species of the Paris basin. M. Dessalines d'Orbigny was the first to reduce the study of these curious organisms to its present form, and the result of his labours, published in 1826,* has constituted the basis of all modern classification of the various species. All the above naturalists, with the exception of Montagu and Stobæus, have referred these chambered structures to the Cephalopoda, arranging them with the Nautilus and the Cuttlefish. Though Montagu held the same view, with reference to most of the species, he pointed out that Troncatulina tuberculata (Nautilus lobatulus, Walker) was found parasitic on Fuci, and being aware that the Nautili are never sessile, he decided that it could not be arranged along with the Cephalopoda. He fell, however, into another error, and placed it, as well as the Miliolæ, amongst the Serpulæ.† Pallas also, speaks

* Tableau Méthodique de la classe des Céphalapodes, Annales des Sciences Naturelles. Vol. vii., p. 96.

† Supplement to the Testacea Britannica, p. 160.

of the fossil Fusulinæ of the limestone of the Volga, as "*small madreporites*," resembling grains of wheat,* though he was probably unacquainted with their affinity to what were then generally believed to be Nautili, and thus he forestalled the discoveries of a later age, only by accident.

M. Dessalines D'Orbigny, especially, adopted the view that the Foraminifera were Nautili, (though he pointed out the Zoophytic character of the animals of the genus Lagena, erroneously separating them from the Polythalamia,) and produced a general classification of the Cephalopoda, in which he comprehended these minute creatures. He ascribed to them an external animal, bearing the form of a Sepia, the shell itself being considered as an internal bone. M. Dujardin, on the other hand, denied that these animals possessed any organic structure, but considered that they consisted only of an animated slime, capable of extension, encased by an indurated external shell, and, regarding them as Infusoria, associated them with the pseudopodian Amoeba.

* Murchison's Geol. of Russia in Europe. Vol. i., p. 87.

A new light was soon to illumine the subject. In 1823 Dr. Ehrenberg visited the Red Sea, along with his friend, Dr. Hemprich, for the purpose of investigating its corals. He soon became doubtful of the Cephalopodous character of the Foraminifera. The rest I will give in his own words. After careful investigations he says —" The result proved that the disk-like shell (Sorites Orbiculus, Ehr. Nummulina Orbicula D'Orbigny) was a polypary, often composed of more than one hundred single animalcules, the cells of which quite resemble those of a Flustra, the animal putting forth and retracting from six to eight tentacula; and I even discovered in the interior of the single cells well-preserved siliceous Infusoria, the last food taken by the animal; and in some of them, also, small globular bodies, which, without much constraint, may be considered as eggs. Though I had at an early period observed that the disk was composed of many cells, yet I could not perceive an opening to them; but the discovery of Infusoria in their interior led me to consider by what means they could have been introduced. Reflection reminded me that I had often seen coral animals, which in their expanded state exhibited many large bodies with tentacula and a large mouth, yet when contracted left scarcely a trace of the openings through which they were protruded from the common polypary. As such I had remembered Pennatula, Lobularia, Alcyonium, and similar forms, in which I had frequently observed that in the skin of the animal existed calcareous particles, which, on the contraction of the skin, so completely closed the opening as to render it no longer perceptible. Renewed examination of the closed surfaces of the cells of Nautilus Orbiculus (Forskal) showed me that in them also dendritic calcareous particles exist, the close approximation of which closes the cell—so that the cover of the cell is in fact the dried up skin of the animal. I now made an experiment in proof by dissolving the small cell in muriatic acid, in order to obtain the animal body in a free state. I obtained as many animalcular bodies as there were cells, connected together by band-like processes, and in the interior of many of them were well preserved siliceous Infusoria. I then treated in the same manner Flustra pilosa and F. membranacea of the Baltic, and found in their interior also, siliceous infusoria."*

* Phil. Mag. Vol. xviii. p. 446.

These views, which first dawned upon the mind of Ehrenberg, in 1823, were fully confirmed in 1839, when he completely established the point that these little animals were not to be grouped with the Cephalopoda, but with the Bryozoa or Moss-corals. He has since examined, whilst in a living state, similar animals discovered in the Baltic at Cuxhaven, and elucidated their history still further. He found that in many cases, the foremost or largest cell, and in some cases the two or three following ones, were filled with transparent parts only, but that in general, from the second cell, all the hinder ones were filled with two differently coloured organs,—what he considered to be the thick alimentary canal, and the granular masses, which he suggested may be ovaries. He also found that they had the power of protruding from the foramina in the skin pseudopodia or extensile tentacula, evidently resembling the contractile fringes of Flustra and some minute Gasteropods. He saw great bundles of filaments arbitrarily ramifying, and though not actually, yet apparently confluent, frequently projecting from the surface, but especially from the umbilical region, where he observes there are perhaps distinct and larger contractile apertures.

Some of the genera, instead of having but *one* series of necks or processes connecting the soft animal contents of the various cells together, have several, which also communicate with the exterior by means of a corresponding number of foramina in front of the last cell, some in the centre, some in the circumference. Alcide d'Orbigny was well acquainted with this fact, and it is surprising that it did not lead him to see the error of regarding these animals as Nautili. He was also acquainted with the pseudopodia, as he says, "L'animal fait sortir des filamens non seulement par les ouvertures du dessus de la dernière loge, mais encore par les pores des côtés des dernières loges."* He still, however, regarded these creatures as possessing an exsertile head, with a plumose feeling and prehensile apparatus, as is the case with the larger Cephalopoda.

In addition to the distinctions already noticed between the Foraminifera and the Nautili, especially that of the soft animal filling every cell in the former, whilst in the latter it merely occupies the terminal one, there are two other marked characters, which separate the Polythalamia from the Cephalapoda. One is, that while the septa

* Voyage dans l'Amerique Meridionale. Tome 5ieme, p. 29.

of the latter are always *concave* anteriorly, in the former they are always *convex.* The other is that, whilst in the Nautilus the tube or calcareous part of the siphuncle, always projects *backwards* from each septum, in Foraminifera the reverse always holds good, two distinctions which are of essential importance in deciding upon their affinities * Owing to the observant genius and skill of Ehrenberg, the opinion that these curious organisms are Bryozoa or Moss corals may now be considered as established beyond all dispute. They are thus brought down from their position amongst the highest and most perfectly developed mollusks to rank amongst the lowest forms of animal life.

There are one or two points connected with their history which I have not found noticed by any of the observers who have written on the subject, and to which I will presently direct attention. The Levant mud contains a great variety of these interesting organisms; indeed, in the time of Soldani (1730), both the Adriatic and the Mediterranean were celebrated for their riches in this department. I have accompanied

* In the genus Endosolenia, Ehr. we have an apparent exception to this rule; but it only presents a single cell.

this memoir with sketches of some of the most characteristic forms.

One of the most abundant is represented by fig. 27, which I am unable, in its young state, to distinguish from Rotalia stigma, of Ehrenberg, but which I believe to be Rosalina globularis, of D'Orbigny. Its outer shell exhibits large and well marked foramina, and through which the pseudopodia have been projected.* Fig. 29 represents the soft animal dried up, and, by some fortunate accident, deprived of its calcareous covering, forming an admirable illustration of the peculiar structure so well described by Ehrenberg. Since discovering the above, I have succeeded in obtaining other specimens, after destroying the calcareous portion, by means of a weak solution of hydro-

* This and several of the other objects have been represented as they appear after they have been rendered transparent by transmitted light. We thus obtain a view analogous to what would be afforded by a section—the only way in which we can study their internal structure. At the same time the plan is very unfavourable to the identification of species, and sometimes even genera, though it is the one adopted by M. Ehrenberg. M. D'Orbigny, on the other hand, always examines them with condensed light as opaque objects—the only way in which the species can be determined, with any degree of certainty.

chloric acid. This specimen assists in the illustration of one peculiar point of their history, about which it appears to me that Ehrenberg is in error, or at least that his choice of illustrations will lead to error in others. Speaking of the Nautilus orbiculus and analogous organisms, (see page 32), and of the orifices in the calcareous portion of these animals, he refers, in illustration, to the dendritic calcareous particles of Alcyonium and other similar forms, which, by a contraction of the skin, close up the external openings, and hence he comes to the conclusion, that, amongst Foraminifera, the calcareous cell is in fact the dried up skin of the animal. Had he concluded that, as in the case of the shells of mollusks, the skin was the chief instrument in the secretion or assimilation of the compound of calcareous and animal matter, which constitutes the shell, it would have agreed with my own observations ; but the inference to be drawn from his language is, that the external shell is the skin itself—the outer and harder integument which binds the soft internal organisms, and which is strengthened in the perfect animal by dendritic portions of carbonate of lime, which, on the alternate expansion and contraction of the cuticle, have the power of opening and closing the foramina.

If I am correct in my interpretations of his views, as gathered from his own illustrations, they differ materially from those to which I have been led, on a close and careful examination of a great variety of specimens.

I am disposed to believe that the calcareous portion, in which only the foramina occur, is a distinct and perfect structure, produced on a similar plan to that on which a mollusk forms its shell—a secretion from an inner skin or membrane, which separates the lime from the ocean, and contributes the animal matter required to render the calcareous particles coherent.* The inner membrane, which envelopes the soft gelatinous tissues of the living animal, is firm and strong, capable of great tension, so that the creature has the power of projecting it through the foramina in the same way as the Echinoderms push their processes through the ambulacral pores, possibly by the injection either of water or of some animal fluid. But I believe that this skin has no more to do with the calca-

* If it is not ultimately found to be a development of epithelial cell-structures, like those in shells, so ably investigated by Dr. Carpenter.

reous portion of the animal, than the shell of a mollusk has with the mantle by which it is secreted; at the same time it *is* a distinct skin, and more dense than the tissues which it encloses. The skin is unconnected with the calcareous portion, for, in drying, it often shrinks away from it into half its original compass, *within* the calcareous cell, the point of concentration being the inner margin of the spire, where it is fixed by the small necks passing through the adjoining septa. I possess a magnificent fossil illustration of this in a flint, from Flamborough Head, where the animal membrane is of such a different colour to the silicified shell, that the forms of both are stereotyped with exquisite beauty. This specimen shows a large interval between the outer walls of each cell, and the membrane by which it was originally lined; reminding one of the way in which the soft portions of Entomostraca shrink, when dried, towards the dorsal portion of their transparent cases. At the same time this membrane is firmer in its texture than the soft parts which it invests. On drying decalcified recent specimens, in order to mount them in Canada balsam, each little bag or segment is found to contain a large air globule, showing that, though the membrane shrinks up to a certain extent, there is a point at which this stops, and then the still softer enclosed tissues dry up towards it, merely increasing its thickness in a small degree, and showing that these inner textures are little more than a gelatinous fluid. Were the whole of the soft animal homogeneous, it would, in drying, either accumulate at some one point of each cell, a small hardened mass, or it would closely invest the whole inner surface of the calcareous cell; but, as we have seen, it does neither the one nor the other, thus indicating that the inner membrane is the true skin of the animal, which invests and holds together its softer and more fluid portions, and which is itself enclosed and protected by a still harder calcareous shell.

I am aware that Milne Edwards has come to a different conclusion with reference to an allied genus of Zoophytes, (Eschara*) but in the detail of his observations, he mentions some facts which indicate a very decided difference between these and the Foraminifera, affording another illustration of the variety of the plans upon which the

* Annales des Sciences Nat. Part Zool. Vol. i. p. 25, 31.

Creator has proceeded even in the production of closely allied groups of objects. One fact noticed by Milne Edwards, is, that in the oldest formed cells of Eschara, the external lines of division become obscure, if not altogether lost, by the addition of new calcareous matter, in which the large apertures alone are left visible—arranged in quincunx,—and he justly contends that this new matter could not have come from the interior. Those who are familiar with Foraminifera, are aware that the exteriors of the earliest formed cells never lose their distinctness, by being thus externally invested with new matter, thickening their parietes.

Another fact is, that on submitting a Polypidom to the action of nitrous acid, "a brisk effervescence was visible immediately, and in some minutes the cells became flexible and separated from one another. Before treating them thus, no distinct membrane was seen on the internal walls of these cells, and when the nitrous acid had destroyed all the calcareous carbonate on which their rigidity depended, *these same parietes still existed, and had not changed their form much ;* only they were formed now of a soft and thick membrane, constituting a bag, in the interior of which we perceived the digestive apparatus of the Polype."*

This is a totally different result from what ensues on submitting a recent Rosalina or Truncatulina to the same test. In the latter case, what is left, instead of preserving the contour of the exterior, is in reality a cast of the interior of the calcareous portion, apparently the identical lining membrane, the absence of which from the cells of Eschara attracted the notice of Milne Edwards. Hence it is probable that the cell of the Foraminifer is more analogous to the poly pedom of the Hydroida, which, Dr. Johnston remarks, is "a sheath, disconnected, or at least not in organic union, with the soft pulpous matter which it invests and protects."

It must be some prolongation of this skin, or membrane, that constitutes the pseudopodia. The latter cannot proceed from the calcareous case, but from the animal contained in it, which pushes them forward through the foramina in the former. At the same time they can scarcely have proceeded as distinct organs,

* History of the British Zoophytes, by George Johnston, M.D. p. 327.

from the centre, passing *through* the elastic skin, or we should surely have found some traces of perforations in the latter, through which they could have been projected. Besides, it accords much more with what is presented by the other inferior animals—to regard the true cuticle as investing, in one form or another, all the superficial extension of the organism. This is the case in the long and beautiful pseudopodia of the Beroë, to which the analogous organs in the Foraminifera bear some slight resemblance.

Fig. 28 represents what I have frequently found in the Levant deposit, as well as elsewhere, and what I believe to be the same species as fig. 26, in an advanced stage of growth. In the young state, the cells preserve the spiral arrangement; as the growth advances, the new cells become less regular in their form, and ultimately appear to be arranged without any order whatever; the later cells have also, invariably, *two* large orifices, one at each end, giving them the shape and appearance of a number of small Cypreæ fixed upon the back of the Rosalina,—the two orifices being analogous to the communications through the septa, which connect the various segments of the soft animal at an earlier stage of growth. This presents another striking difference from anything that has been seen amongst the Nautili, but at once reminds us of the investing Corallines. These new cells have either been soft germs, which have escaped from the interior, and fixed themselves on the backs of their parents, or they have been produced by that process of budding, or gemmiparous generation, so common amongst the lowest animals.

Fig. 30 represents an elegant species of Polystomella, allied to P. crispa. In this instance, instead of the segments of the animal being connected by *one* chain of necks passing through the septa, there are a considerable number, which, when viewed in front of the anterior cell, are seen, in this genus, to be arranged so as to represent two sides of a triangle ∴. These apertures are situated close to the point of junction, between the septa and the lateral parietes of the cell.*

Figs. 31 and 32 represent young and old forms belonging to the allied genus Peneroplis, where, instead of the perforations being arranged

* The plate gives a less faithful representation of this animal, viewed as a transparent object, than I could have wished.

round the outer margin of the septa, they form one or more straight lines in its centre. The specimens are also represented as transparent objects, viewed by transmitted light,—by which means a section of the shell is obtained. In the young animal, Fig. 32, it will be seen that only one communicating canal connects the different cells, whilst in the older specimens, these gradually increase in number, until in the outer septa we find several.* The drawing, Fig. 32, also shews the curious thickening of the ring round the septum, which gives the projecting form to the siphuncle—the upper lip being incurved—whilst the lower one assumes the aspect of an obtuse tooth. Fig. 31 shews that the incurved appearance is continued through the whole shell, but only in the outermost series of canals.

Fig. 34 is a beautiful Planorbis-like form, of which I have not been able to identify the genus. It is curious as exhibiting no trace whatever of concamerations, though the large and beautiful

* This indicates that Ehrenberg's division of these animals into Monosomatia and Polysomatia is not a natural one, as in the young state the Peneroplis would belong to the one division, and, in its mature form, to the other.

perforations leave no doubt as to its being one of the Foraminifera. I shall afterwards have to notice a similar form found in the Lias by Mr. Strickland.

Fig. 35 represents the inferior surface of a Truncatulina, which I believe to be the T. tuberculata, a complete cosmopolite. The channel of communication between the cells is most distinctly seen along the umbilical margin of the outer ones.

Figs. 36, 37, and 38 represent various forms of the family of Plicatilia of Ehrenberg, the Miliolæ of older authors. The two former belong to the genus Spiroloculina (D'Orbigny). Fig. 38 is, apparently, a Biloculina,—38, *a*, exhibits it as an opaque,—and 38, *b*, as a transparent object. The singular forms of the Miliolæ occur at the present time in sand brought from most parts of the world. They are abundant on our own shores. I have received them from the West Indies, the Phillipine Islands, and a variety of other distant localities, whilst we shall find that analogous genera constitute the greater portion of some tertiary deposits. They are not found in rocks coæval with, or older than the

W C Williamson Del.

J. Stephenson & Co Sc.

chalk. Though not distinctly concamerated, there is generally some constriction to be observed at each turn of the spire,—a rudimentary approximation to the septa of the higher forms. The construction of the lip in fig. 37 shows an approximation to the model which nature has followed in the Peneroplis, fig. 32.

Fig. 33 represents a beautiful species of Textillaria, with very distinct foramina,—a genus which is of great geological interest, as constituting so large a portion of the Chalk rocks.

Fig. 39 is an example of the curious genus Lagena. I have also observed numerous specimens of a closely allied species which occurs on our own shores—Lagena globosa—and to which I shall have to refer again.

Associated with these Polythalamian corals there are also found, in the Levant mud, numerous fragments of minute forms of Flustra and other allied Corallines.

I have also met with some examples of another class of microscopic organisms—the Siliceous

Infusoria, as they are generally designated,—specimens of the three genera, Campylodiscus, Coscinodiscus, and Actinocyclus having come under my notice. It is anything but certain that these curious and beautiful creatures do not belong to the same group as the Diatomaceæ, and that they have in reality no claim to the possession of animal life. In so many points they resemble the siliceous frustules of the former, that I cannot believe them to be distinct. Let any one, to satisfy himself of this, examine and compare a few genera in the following order, —Coscinodiscus, Actinocyclus, Actinoptychus, Heliopelta, Podiscus, Systephania, Triceratium, Zygoceros, and Biddulphia.

In Coscinodiscus, Actinoptychus, and Actinocyclus we have the elaborately ornamented circular disk. In the three following genera we find various forms of projections arising up from the external rim of these disks. In Heliopelta these are usually sharp points, but in Podiscus they are obtuse protuberances, very like those forming the angles of many Diatomaceæ. In Triceratium we have very similar appearances, only the circle has degenerated into a triangle, with one projection at each corner.* Viewing the lateral aspect of Triceratium Favus, under a low magnifying power, it is often scarcely distinguishable from the lateral view of Zygoceros Rhombus, and of short frustules of Biddulphia aurita, both of which are well known to occur in the peculiar chains, so common amongst the Diatomaceæ. I cannot help thinking, that when our knowledge of Triceratium and its analogues is more extended, we shall find some of them also occurring in chains. Systephania, a disc closely resembling Coscinodiscus lineatus in other respects, has two of these lateral projections, which, according to Dr. Bailey, do connect distinct individuals in their young state; an exact analogue of what we find amongst the Diatomaceæ.† In passing from Triceratium Favus to Zygoceros, we lose the beautiful reticulated structure, but this returns in Biddulphia pulchella, so that it does not affect the argument. The mode of their development, also, so far as our imperfect knowledge of it goes, appears to favour the idea of a connection be-

* Amongst some objects from the Phillippine Islands, sent to me by Dr. Bailey, is a form identical with Triceratium Favus in every respect, except that it is quadrangular.

† Dr. Bailey on some new localities of fossil and recent Infusoria. Silliman's Journal. Vol. 48.

tween the Coscinodisci, &c., and the Diatomaceæ. Ehrenberg considers that the former do not occur in chains, though they exhibit the peculiar phenomenon of self-division, so common in the lower tribes of both plants and animals; a double septum being formed in the interior of the siliceous cell or frustule, which encloses the soft colouring matter, so that each half thus becomes an independent organism. The general definition of this curious mode of increase, as given by Ehrenberg, is that "Two individual bodies originate from one individual body, each of which two, possesses and actually is the half of the other, which half perfects itself to its separate and closed individuality. This completion is effected by an internal activity allied to regeneration *called into activity, by the mere tension of the parts*."* The former part of this definition appears to be in accordance with the observed facts, and, as far as the *soft* structures are concerned, the latter also; but that it can apply to those, whose hard, fragile and unyielding siliceous cases present anything but a plastic material, capable of tension, is very questionable. It appears more probable that the soft

* Taylor's Scientific Memors. Vol. iii. Art. 10.

internal organisation may separate into two parts, according to Ehrenberg's definition, but that the subsequent formation of the two transverse siliceous septa is owing to the performance of some act vaguely analogous to secretion, concerning which little is really known—each portion of the endochrome closing up its own half of the original cell, before these separate. Indeed, in many species, two new and distinct frustules form within the interior of a larger one, and are liberated only by the breaking up of the latter. This is what we see in Isthmia and Biddulphia, and is manifestly distinct from the "mere tension" of Ehrenberg.

Whatever may be their nature, the siliceous cases of these organisms occur in oceanic deposits from almost every part of the globe. In the Levant mud however, they are not very numerous, when compared with other structures. As is well known, they occur in the greatest perfection and abundance in the deposits of Bermuda and Virginia,—fields, in which Dr. Bailey and his American coadjutors have won such lasting fame. Fig. 23 represents a small species of Campylodiscus.

The next structures contained in the Levant mud to which I would direct attention, are the fragments of Pinnæ, and other shells. The examination of shell-structures, now going on in the able hands of Dr. Carpenter, has already opened a new field of enquiry, and promises to place in the hands of the Zoologist and the Geologist, an instrument of great value, applicable alike to the identification of both recent and fossil shells: — one by means of which many cases of doubtful affinity have been already cleared up, and the identification of imperfect fragments rendered much easier than before. Many of those in the Levant deposit, are thin laminæ, which have separated transversely to the direction of the prisms; but there are also numbers of these calcareous prisms, which, by the decay of the shell membrane, have been detached from one another. They exhibit a great tendency to break up in a direction parallel to the transverse lines which mark the original epithelial layers, producing small calcareous granules, of a semicrystalline aspect,—such as a very moderate amount of either chemical action, or mechanical attrition would so modify, in outward appearance, as to render the identification of their organic origin, a matter of some difficulty. They would have much of the aspect of the crystalline atoms, found in many strata, which have been supposed to result from chemical precipitation. This tendency to separation, existing amongst shells, is important in its bearing upon the origin of calcareous rocks, and one to which I shall have to recur.

Numerous fragments of Echinodermata may also be observed. Some of these are the partially developed rudimentary plates, as in Figs. 50, 51, 52.* Others consist of the cribriform fragments of matured animals, Fig. 53—easily identified by those who are familiar with these interesting organizations. There are also some Cytheræ—minute marine Entomostracous Crustaceans—allied to the genus Cypris, so common in our fresh-water pools.

Before comparing the result of a microscopic examination of the Levant mud, with what is observed on an examination of the older strata

* See Agassiz' Monographies d'Echinodermes vivantes et fossiles—quatrième livraison. Anatomie du genre Echinus par G. Valentin. Table 5., figs. 65, 66, 67.

of chalk and limestone, I would direct attention to a few other recent and tertiary deposits, which help to illustrate the subject, and show some of the links which connect the existing with the more ancient phenomena.

On most of our English coasts, extensive deposits occur, which are largely composed of comminuted shells and corals; whilst various forms of unbroken Foraminifera and some Cytheræ are scattered through the pulverised mass. The two latter generally constitute but a small proportion of the calcareous matter, though in some cases they are much more numerous. The whole is usually mixed up with different inorganic substances, as sand, carbon, aluminous and micaceous earths, varying according to the locality from which they are obtained. On the Yorkshire coast the first two prevail. On those of Wales, especially near Tenby, the specimens I have examined contained a larger proportion of the latter, derived from the primary schistose rocks of the neighbourhood. These recent accumulations have been known to most conchologists during the last two centuries. On a detailed examination of the genera of Foraminifera found on our coasts. we shall subsequently see that they bear a considerable resemblance to those occurring in many portions of our English Chalk. The most generally diffused are the Rotalinæ. Rotalia Beccarii and Truncatulina tuberculata (Nautilus lobatulus, Walker) occur on almost every beach. Cristellariæ are found in some localities, and in addition to these, we find forms of Textillaria, Verneueilina, Polystomella, especially P. crispa, Nodosaria, Dentalina, Marginulina, Triloculina, and Quinqueloculina, in various degrees of abundance, many of the recent British forms being identical with those found in a fossil state, Associated with these we have abundance of minute Corallines, Cytheræ, sponge spicula, both siliceous and calcareous—spines and fragments of Echinoderms, with myriads of young and broken shells. These are not mere local accumulations. The extensive beaches of the Yorkshire coast are mainly of this character, containing from ten to sixteen per cent of calcareous matter, and I presume that those of other parts of England present similar results. They do so wherever I have had the opportunity of examining them.

Portions of a similar accumulation at Key West Florida Keys, U.S., sent to me by Dr. Bailey, exhibited corresponding results. There were various Foraminifera, especially Miliolæ, mixed up with sponge spicula, small corals, broken shells, and rudimentary plates of Echinodermata, along with a small proportion of sand and amorphous matter.

Mr. Reckitt has furnished me with some sand obtained from an interesting and somewhat analogous accumulation seven feet below the surface, at Boston, in Lincolnshire. It is unquestionably part of an ancient sea-beach. There is no doubt but that a considerable portion of the fen district to the west and south-west of the Wash, was once an estuary, which has undergone considerable changes, even since the time of the Roman Invasion, the old sea-bank having, at that comparatively recent period, been much further inland than at present.* The Boston deposit consists principally of very fine sea sand and carbonaceous matter; but mixed up with it are an immense number of Foraminifera, of several species, some of them being identical with those of the Levant. The most numerous of these are

* As in the case of the Lewes Levels. Lyell's Principles of Geol. Vol. iii., p. 210, second edition.

Rotalia Beccarii, two or three species of Polystomella, Rosalina globularis, identical with those from the Levant (Figs. 26 and 28), Textillaria —several species, one of which is identical with Fig. 33; another so closely resembling T. globulosa, (Ehr.)—the species so common in the Chalk as not to be distinguishable from it. The most interesting feature in this deposit is the comparative abundance of the genus Lagena of Walker, and our older conchologists. I have already detected L. striata, L. lævis, L. globosa, L. marginata, L. squamosa, and one or two additional undescribed species.* The deposit

* It appears that out of the genus Lagena, Ehrenberg has constructed the two genera,—Miliola and Endosolenia. Dr. Bailey has sent me Lagena striata, from the Miocene Tertiary strata of Petersburg, U.S., under the name of Miliola Ficus, which name he received from Ehrenberg, and along with it, from the same stratum, was Lagena globosa, named Endosolenia miliaris (?) This division of the genus is exceedingly proper, and shows the occasional value of examining these creatures as transparent as well as opaque objects, characters being thus sometimes discovered which would otherwise be overlooked. Lagena globosa exhibits, when thus examined, a long tube with a patulous extremity, projecting downwards from the terminal orifice into the interior of the cell, sometimes being so short as to be scarcely visible, at others so long as nearly to reach the opposite extremity of the cavity. This character Ehrenberg appears to have had in view, in employing his very

also contains numerous spines and other portions of Echinodermata, many beautiful Cytheræ, and some fragments of shell textures, amongst which Dr. Carpenter pointed out to me a fragment of one of the perforated Terebratulæ. Here we have the elements of a mixed stratum, where all the atoms of calcareous matter were once living organisms, and those chiefly minute Foraminifera, but where the siliceous portion is entirely inorganic, unmixed, to any material extent, with either siliceous Infusoria

expressive generic term—Endosolenia. After the examination of a vast number of specimens, I find that Lagena marginata and L. squamosa belong to the same genus, exhibiting a similar internal sheath, whilst L. lævis and probably L. retorta belong to the same group as L. striata—Ehrenberg's Miliola Ficus—having a long external neck or tube. It is to the internal sheath of Endosolenia that allusion was made in page 35, as constituting an apparent exception to the general rule in the structure of the Foraminifera. Lagena squamosa (Vermiculum squamosum Mont.*) is, I have no doubt, identical with the L. reticulata of Mr. McGillivray;† when viewed under the microscope, a little out of focus, the reticulations exhibit all the squamous appearance represented in Montagu's figure—an effect that would be sure to be produced by the imperfect instruments of that age.

* Montagu's Testacea Britannica. Table 14, fig. 2.
† Shells of Aberdeen.

or Diatomaceæ ; as yet I have detected neither, though some few doubtless may exist, but certainly not in sufficient abundance to constitute, in any subsequent re-arrangement of the elements, a siliceous substance resembling flint.

Recent calcareous sand, obtained from the West Indies, presents very similar appearances to what I have described in that from the Levant. We have a similar accumulation of minute and perfect Foraminifera, of the genera Rotalia, Polystomella, Peneroplis, and the group of Miliolites; a still larger proportion of fragments of the same creatures; multitudes of minute corals, belonging the groups Escharina and Celleporina; several forms of calcareous and siliceous spicula of sponges; some calcareous granules, probably derived from the disintegration of the larger corals, and a small admixture of siliceous particles,—apparently common sand.

Specimens of the newer Pliocene deposits of Barbadoes present corresponding results, with the exception that the organisms are not so numerous. The majority of the specimens which I have examined, consist chiefly of semicrystalline granules of Carbonate of Lime, which cannot be distinguished from the residuum obtained on crushing the common Madrepora muricata; I have little doubt but that they have been largely derived from the disintegration of the hard calcareous corals, existing species of which abound in the stratum. But, along with these we find Rotaliæ, Marginulinæ, and Miliolites.

In the newer Pliocene deposits of Sicily, we obtain similar evidences of a slow organic accumulation, only in a more marked degree. Rotaliæ, Textillariæ, Miliolites and small corals, (Escharinæ and Celleporinæ) in a perfect state, are still more abundant, whilst in a fragmentary form they constitute a considerable portion of the mass. Along with them are some siliceous sponge spicula, spines of Echinoderms, and a few calcareous granules, probably derived, as before, from the hard corals and larger shells.* The

† Amongst these Sicilian deposits Ehrenberg found some strata containing multitudes of the so-called siliceous Infusoria, along with Foraminifera; and, from the apparent identity of the latter with species found in the Chalk, he concluded, contrary to the views of most other geologists, that the Tertiary strata of Sicily, were in reality Cretaceous. This erroneous opinion, however, he has since withdrawn.

specimens which I examined, and for which I am indebted to the kindness of the Marquis of Northampton, by whom they were collected, are chiefly from the limestone in the vicinity of Palermo, connected with the tertiary formations of Sicily.* Speaking of a portion of this deposit at Spaccaforno, Mr. Lyell observes, that "it is, for the most part, of a pure white, often very thick bedded, and occasionally without any lines of stratification. This hard white rock is often four or five hundred feet in thickness, and appears to contain no fossil shells. It has much of the appearance of having been precipitated from the waters of mineral springs, such as frequently rise up at the bottom of the sea, in the volcanic regions of the Mediterranean. As these springs give out an equal quantity of mineral matter at all seasons, they are much more likely to give rise to unstratified masses than a river which is swollen and charged with sedimentary matter of different kinds and in unequal quantities, at particular seasons of the year.†

However this may apply to the deposit at

* See Lyell's Principles. Vol. iii. p. 320.

† Lyell's Principles. Vol. iii. p. 220.

Spaccaforno and the south of Sicily, it obviously will not account for the origin of the same formation at Palermo, and it is not improbable that the application of the microscope to the former would lead to results similar to what we obtain from the latter.

Older Pliocene Strata.—English Crag. In this very variable deposit, the greater portion of the organised fragments consist of shells, corals, and Echinodermata. Mr. Searles Wood, in 1835, observed that amongst these, Foraminifera were abundant, as even at that time he had discovered fifty species in the lower Crag formation of Suffolk alone.* In some of the Coralline Crag of Suffolk, furnished to me by my friend Mr. Charlesworth, I found Foraminifera, especially Textillariæ, calcareous shell prisms, broken shells, small corals, and, in one instance, a stellate spiculum of a sponge, resembling those of the recent Tetheia.

In the older Miocene strata of Petersburg, in Virginia, we have various Foraminifera, especially Rotaliæ, Textillariæ, and Miliolæ, especially Biloculinæ and Spiroloculinæ, with spines of Echi-

* London and Edinburgh Phil. Mag., August, 1845, p. 86.

nodermata, Cytherinæ, and a large quantity of amorphous earthy matter. Allusion has already been made to the resemblance between some of the fossils from this stratum and those from the Boston sand. The Lagena striata and L. globosa are identical, as well as several of the Cytherinæ, and I believe also, some of the Rotaliæ.

Eocene Strata.—Paris Basin. The labours of Deshayes, Brongniart, Lamarck, and D'Orbigny, have long since made us familiar with the exceeding richness of the marine strata of the Paris basin in Foraminifera.* Some of the leading forms have been figured by D'Orbigny, Lamarck, Lyell, and others. But the application of the microscope to the deposits shews, that where they do not degenerate into arenaceous strata, they not only

* The Calcaire Grossière of that extensive basin is in certain places so filled with Foraminifera, that a cubic inch, from the quarries of Gentilly, afforded 58,000, and that in beds of great thickness, and of vast extent. This gives an average of about 3,000,000,000 for the cubic metre. (Alcide D'Orbigny on the Foraminifera of America and the Canary Islands. Edinburgh New Philosophical Journal. Vol. xxxii. p. 3. 1842.)—M. D'Orbigny also remarks, that "this group of animals is not less abundant in the Tertiary formations extending from Champagne to the sea, and its numbers are prodigious in the basins of the Gironde, of Austria and of Italy. (Idem, p. 3.)

contain, but almost entirely consist of similar organisms. In their richness, as to number and beauty of species, they almost rival the deposits of the Levant. The greater number of the forms visible to the naked eye are well known to belong to Ehrenberg's family of Plicatilia, especially to the genera Triloculina and Quinqueloculina. In some localities these abound to an almost incredible extent. Under the microscope we also find Rotaliæ, Textillariæ, beautiful forms of Peneroplis, Calcarinæ, Nodosariæ, acicular and triradiate spicula of sponges, small corals, and calcareous prisms of shell structures. The minute cementing portions of the stratum consist chiefly of fragments of the same animals. We find few of the semicrystalline granules which constitute so large a portion of the Barbadoes deposit. If these semicrystalline granules are to be ascribed to the disintegration of the hard corals, such a result was to be expected, a priori, from the rarity of these fossils in the Paris basin, when compared with some of the recent Pliocene strata in the West Indies, in which Madrepora muricata, and other species still found in the tropical seas, are abundant.* The Eocene marl of Pamunkey river,

* In 1834, Lieut. Nelson, in his paper on the Geology of Bermuda, pointed cut the existence of beds of limestone

Virginia, for specimens of which I am indebted to Dr. Bailey, is exceedingly rich in various organisms, consisting chiefly of Polythalamia, spines of Echinodermata, broken shells, and calcareous shell prisms, Cytherinæ, sponge spicula, rounded sand particles, as well as small angular grains of green Silica, such as we find in our English greensand, and which have probably been derived from the destruction of some of the older strata. A Tertiary marl from New Jersey, supplied to me by Professor Ansted, of the exact age of which I am ignorant, presented very similar results.

London Clay. So small a portion of this stratum contains anything like the amount of calcareous matter found in the preceding cases, that we should not expect to find the calcareous animalculites in any great abundance; the British strata of this era contain so much larger a proportion of aluminous and siliceous elements, probably the detritus of the older rocks. Dr.

and calcareous sand derived from comminuted shells and corals. He observes, "From the most compact rock to the very sand of the shore, the materials are universally fragments of shells, corals, &c."—Trans. Geol. Soc. Second Series. Vol. v. p. 110.

Mantell has shewn that Foraminifera exist in clay obtained from a well at Clapham, and they had previously been observed by Mr. Wetherell in the clay obtained from a well, dug on the south side of Hampstead Heath.*

Mr. Darwin has kindly obliged me with specimens of many of the Tertiary strata brought by him from South America, some of which present singular differences from the majority of those which I had examined from the United States and elsewhere. In none of the specimens examined did I find one Foraminifer, and in only two did I detect any siliceous organisms. One of these was the specimen from Port St. Julian, in Patagonia, alluded to in his published Journal, as having been examined by Ehrenberg.† In this deposit, which was part of a stratum eight hundred feet thick, were a variety of siliceous discs, &c. some of them of great beauty, and a few sponge spicula. The substance of which the stratum consisted, is not in the form of rounded sand

* Trans. Geol. Soc. Second Series. Vol. v. p. 131.

† Darwin's Journal of a Voyage round the World. Second Edition, p. 171.

grains, but of particles of glassy Felspar, which exhibit a number of parallel grooves, and curious circular cavities.* This peculiar cancellated structure of the Felspathic fragments is even still more marked in the Tufaceous layer of Rio Negro. The fragments of Felspar bear no resemblance whatever to the sand grains of ordinary recent deposits. This specimen appears to contain neither Polythalamia nor siliceous organisms.†

The other deposit which contained microscopic siliceous organisms was the bone bed of Punta Alta, Bahia Blanca,‡ in which I found a few discs identical with some from St. Julian, and also a few broken spicula. No calcareous organisms were visible, but amongst the large grains of sand was much amorphous matter, which contained some Carbonate of Lime. I could, however, detect no organic structure in the calcareous particles. The deposit contains both shells and bones. I also obtained Carbonate of Lime from

* I am indebted to Mr. Darwin for pointing out to me that these particles consist of fragments of glassy Felspar, which have resulted from the long-continued attrition of erupted rocks.

† Darwin's Journal. Second Edition.

‡ Darwin's Journal, p. 83.

the Mammiferous deposit of the Pampas, at M. Hermoso, from the impure Gypseous strata of the Cordillera of Central Chili, and from most of the specimens from the older Patagonian Tertiary deposits. In those from St. Joseph's Bay were a large quantity of sand grains and much amorphous matter, which latter contained calcareous elements, along with some calcareous shell prisms. Specimens of soft Sandstone from St. Fé, abounding in extinct shells, consisted chiefly of sand grains, and appeared to contain no calcareous matter except what was in the form of broken shells and detached shell prisms. When treated with Nitric acid, there was but little effervescence.

A singular crystalline limestone from the same locality, reminded me in its aspect, under the microscope, of the Pudding-stones from the Wiltshire green sand, being full of small rounded siliceous granules, only the cementing portions consisted of a crystalline calcareous substance, in which I could not succeed in detecting any microscopic organizations whatever. It dissolved in Nitric acid with a rapid effervesence, and contained 28.54 per cent of Carbonate of Lime. One of the older Tertiary strata from Port Desire, St.

Cruz, contained sand grains, fragments of glassy Felspar, like that from the St. Julian deposit, probably a few sponge spicula, and much calcareous matter in the form of shelly fragments; the latter presenting very little visible structure. It dissolved in Nitric acid with much effervescence, containing 40.33 per cent of calcareous matter.

Specimens from Mocha, Chili, contained a large amount of sand, some glassy Felspar, and 57.61 per cent of amorphous lime, but no microscopic organisms.

Another from Coquimbo, Chili, presented analogous appearances, containing 53.79 per cent of calcareous matter, but no visible microscopic organisms.

Some from Nosidad, Chili, exhibited sand, and perhaps some glassy Felspar; some shreds and prisms of shell structures, constituted the only calcareous portions, amounting to 1.53 per cent.

A white calcareous specimen of the old Tertiary formation from the west part of the Banda Oriental, contained 56.79 per cent of inorganic atoms of lime, along with some sand. This is a very singular and Chalk-like rock, but my specimen contains no trace of microscopic organization.

A pure white specimen of the Estuarian marl of the Pampas,* exhibited very similar results, with the exception of a few delicate white threads resembling very small branching corals. I have not, however, been able to satisfy myself of their organic nature.

A brown coloured specimen from the same deposit contained a much larger amount of sand and silt. The lime was apparently diffused through the whole, and under the microscope was undistinguishable from the mud.

A green siliceous rock from New Jersey, very like our English lower green sand, (sent me by Professor Ansted,) in which the shells still retained their calcareous organization, exhibited large rounded grains, of very dark green sand. Amongst them were a few Foraminifera, and in some specimens numerous detached shell prisms,

* See Darwin's Journal, p. 149. First Edition.

thus exhibiting a stratum which is almost entirely siliceous, with the exception of a few minute and scattered calcareous organisms. It is possibly of the age of our cretaceous rocks.

Thus far we find that, with the exception of the South American strata, the deposits have been formed by agencies very similar to those still operating in our seas, and on our sandy beaches. That where any large amount of calcareous matter is present, such as cannot be accounted for on the supposition of detritus from more ancient strata, there we usually find either Foraminifera or disintegrated shell structures. Where we have extensive siliceous strata, containing siliceous organisms, but none of a calcareous character, we have in all probability deposits in which chemical agencies have effected great changes. But to this subject we shall have to recur. Let us now see how far down the geological scale similar illustrations are to be found.

Cretaceous Strata.—As before stated, several observers have examined the Chalk rocks since the first discovery of the fact, that they chiefly consist of minute Polythalamia. This has been especially done by M. Ehrenberg and M. Alcide

D'Orbigny, for abstracts of whose masterly papers we are indebted to Mr. Weaver.* The general result at which all have arrived is, that Chalk contains vast numbers of minute organisms, especially Foraminifera, to which the deposit principally owes its origin.

The Cretaceous strata in which the structure of these organisms appears to be the least altered, are those of the Upper Missouri, U.S., in which some of the species are identical with, and others have a close affinity to those from the Chalk of our own island; Rotalia globulosa (Ehr.) and Textillaria Americana (Ehr.) being the most common, the latter replacing the T. globulosa (Ehr.) of Europe. They still present the vitreous and transparent appearance, which characterises similar forms of Rosalinæ and Rotaliæ in a recent state; along with these, the same deposit also contains a large amount of opaque amorphous calcareous matter, very different in its character from what would be presented by the hyaline fragments of Rotaliæ, in an unaltered state.

Chalk from Dover, for which I am indebted

* Phil. Mag., London and Edinburgh. Vol. xviii. p. 375, and Annals of Nat. Hist. June and July, 1841.

to my friend Dr. Mantell, is exceedingly rich in analogous forms, only the finer portions are more obviously the direct result of the breaking up of the larger Polythalamia. We also find numerous calcareous shell prisms (looking very like sponge spicula), fragments of larger shells, especially Terebratulæ and Inocerami, with some portions of Echinodermata, readily distinguished by those whose eye is familiar with recent examples of the same structures.

Chalk from the midland counties presents us with similar results, varying, at different localities, as to the distinctness of the organisms, the amount of amorphous matter, and the abundance of shell prisms. The Yorkshire Chalk, which is more compact, exhibits similar structures, though they are less easily separated from their amorphous cement, and in some specimens so broken up as to present few perfect organisms ;—as if the newly forming stratum had been acted upon by gentle aqueous currents, which had transported the more minute atoms to another locality, where some local interruption to the current allowed this sediment to be re-deposited, giving rise to layers of denser structure and finer grain. The Red Chalk, which is of a bright red colour, from being loaded with an oxide of iron, presents identical organisms. They also exist still lower down, in the Grey Chalk, which passes into the blue clays of Speeton.

William Harris, Esq. of Charing in Kent, and Dr. Mantell, have submitted to my inspection specimens of a deposit of chalky marl, which was discovered by Mr. Harris, at the foot of the Chalk hills, at Charing. The deposit, resting upon the upper Green-sand is about a foot thick, chiefly consisting of soft white tenacious clay; but contains vast numbers of the beautiful Foraminifera, and other organisms characteristic of the Chalk, and which Mr. Harris has distributed with the utmost liberality amongst those who are interested in the subject. Its origin appears to be somewhat obscure, but, as Mr. Harris suggests, the most probable explanation is, that it was formed at the time the Chalk hills obtained their present undulated contour, and that the deposit in question was some of the resulting debris. Plate 4, is devoted to some of the very beautiful organisms which the clay contains. They are easily separated by washing, and become as clean and perfect as they could be, even in the most recent deposits.

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In addition to what I have enumerated, the deposit also contains several additional species of Foraminifera and Entomostraca, which I have not figured, as well as a great variety of Amorphozoa, Zoophytes, Anellida, as well as fragments of various Crustacea, Echinodermata, Conchifera, Brachiopoda, and Cephalopoda, along with small teeth and bones of fishes, which have been found in it by Mr. Harris.

Figs. 56 and 57 represent the upper and under surfaces of a large species of Rotalia of Ehrenberg, but which may belong to D'Orbigny's genus Rosalina. I cannot perceive the oral aperture which, by the present mode of classification, is necessary to the positive identification of the genus. This species is very abundant.

Fig. 58 I believe to be the Rotalia (Planularia) turgida of Ehrenberg. It belongs apparently to the genus Robulina of D'Orbigny. The aperture is distinctly at the external angle of each cell, and not at the inner border, as in Rotalia.

Fig. 59 is probably the early condition of some other species, though the small central disc on one side resembles Anomalina (D'Orbigny); various modifications of it are abundant—some with no traces of divisions into cells, others with two or three. It can scarcely belong to fig. 56, as the latter shows the division into minute cells to the apex of the spire. It has the central disc of an Anomalina.

Fig. 60 is the Rotalia globulosa of Ehrenberg, of which exquisitely beautiful little specimens occur not unfrequently.

Figs. 61 and 62 represent forms of Textillaria, which vary considerably.—Fig. 61 is, appparently, the T. globulosa. (Ehr.)

Fig. 64 exhibits a front view, and 65 the base of what is probably some genus allied to Textillaria. It is an indistinct spiral, of a trochoid form. In some parts of the spire there are vague traces of divisions into cells. The base, fig. 65, exhibits a well marked terminal cell, occupying nearly the half of the circle. The smaller depression is apparently but partial, and does not constitute a septum.

Fig. 63 probably belongs to D'Orbigny's genus

Verneueilina. It is triangular, the edges being sometimes sharp and produced. The lines of division into chambers are very indistinct. The species is common. This species, or one very closely resembling it, is in the cabinet of Mr. Bean, of Scarborough, who obtained it from the Irish coast, and who also possesses, from the same locality, specimens not to be distinguished from figs. 61, 62, and 64. In the recent state, all these forms present an opaque aspect, very different from the glassy transparent appearance of the Levant Textillaria. The fossils exhibit the same opacity.

Fig. 66 is a species of Marginulina, there being a distinct projection at the superior angle of the last chamber, in which the terminal orifice is situated.

Fig. 67 is a beautiful Cristellaria (D Orbigny), exhibiting an excellent illustration of the tendency of the straight forms to assume the spiral type. It is little more than a straight Marginulina, with the young cells incurved.

Fig. 68 is probably another species of the same genus.

Figs. 69 and 70 are two species of Dentalina (D'Orbigny). In the former, the cells are longitudinally striated, and in the latter smooth I have seen some examples like fig. 69, but in which the axis was straight, instead of being curved, and which, consequently, would belong to D'Orbigny's sub-genus Nodosaria. Fig. 72 exhibits a small sectional view of fig. 70.

Fig. 71 belongs to the recent genus Lagena, or to Oolina of D'Orbigny.

Of the nature of the two bodies figs. 73 and 74, I have not been able to form an opinion. They are small flask-like objects, curiously echinulate, the projecting spines being sharp and transparent. They very much resemble some recent Lagenæ, only the latter are, I believe, always equilateral. Mr. Harris suggests that they may be fragments of Dentalina aculeata, D'Orbigny.

Fig. 75 represents a lateral, and fig. 76 a dorsal view of a very beautiful Entomostracous animal, which may be conventionally arranged under the genus Cytherina. It is remarkable for the singular series of marginal tubercles, or projections, of which the arrangement varies in different specimens, the row fringing the broad extremity, being the most constant. The irregular projecting surface is marked with delicate reticulations. As I believe it has not been figured, it may be provisionally called C. echinulata.

Fig. 77 is either another species, or, what is possible, a young state of the last.

Fig. 78 is an exquisitely elegant form, belonging to the same class of objects. It is shaped like an Arca, with two lengthened projections at the umbones. I have seen several specimens of it. C. umbonata would be an appropriate name.

Fig. 79. Some forms of this species seem to approach to young states of fig. 75. It is possible that they may be identical. Many recent Entomostraca vary considerably at different stages of growth. As, however, I have seen several specimens of it, and they seem constant in form, the name of C. serrata may be given to it.

Fig. 80 is the most common species, examples of it being of frequent occurrence. Recent species closely resembling the above forms, occur in modern beach deposits.

Fig. 81 is almost the only fragment I have seen in the Charing Chalk really resembling a sponge spiculum, of which it may possibly be a portion.

Fig. 82 is a calcareous tri-radiate sponge spiculum, from Chalk found, by Dr. Mantell, in the interior of a hollow flint :

Fig. 83 is a siliceous sponge spiculum, found abundantly along with the last.

Fig. 84 is a fragment of shell, and figs. 85 and 86 are detached calcareous shell prisms, which are very abundant in the Charing Chalk. At first I was led to suppose that these were large calcareous sponge spicula, but, on further examination, I was convinced that they were shell prisms, and that the analogous structures found in flint were of the same nature. I am happy in having had an opportunity of obtaining Dr. Carpenter's confirmation of the views which I ventured to publish,* on the character of these curious forms. After examining my specimens, he had no doubt but that they were the separated prisms of shells, probably Inocerami.

I have noticed all these minute organisms somewhat in detail, as they afford one of the most interesting examples of the variety of microscopic fossils which constitute Chalk that I have met with. With one or two exceptions I have not ventured to attach any specific names to the Foraminifera, many of which are probably included in M. D'Orbigny's catalogue;† but as neither descriptions nor figures accompany the list, and I have had no opportunity of consulting the plates accompanying his original memoir, I have no means of identifying them; and to coin new terms would only be to add to the confusion which is already too great, owing to the fact that D'Orbigny and Ehrenberg are adopting two distinct and independent systems of specific nomenclature, based upon different modes of observing.

*On the real nature of the minute bodies in flints, supposed to be sponge spicula. Annals Nat. Hist. Vol. xvii. p. 467.

† Phil. Mag. Lon. and Edin. Vol. xviii. p. 416.

The ferrugineo-calcareous matter obtained from the decomposing sponges of Flamborough Head, contain abundance of large and perfect Foraminifera, and in some specimens calcareous sponge spicula are distinctly present. All that I have examined contained a much larger proportion of sand grains, than occurred in the surrounding Chalk. Thin argillo-calcareous partings separate the horizontal beds of Chalk at the same locality, but they exhibit nothing more than a few Foraminifera, amongst some sand, and much amorphous argillaceous matter. They evidently indicate the occasional overflow of muddy water, from some source not far distant. The partings do not usually extend over very wide areas, but appear to have arisen from local causes. Siliceous granules are more or less abundant in every specimen of Chalk which I have seen, and also in that taken by Dr. Mantell, from the hollow flint. The lime of some of the calcareous Rotaliæ from the chalk in the same flint has disappeared, and its place been supplied by pure and transparent silex, which is the condition of nearly all the Foraminifera found in the solid flint—a curious illustration of the preference manifested by the siliceous matter for combination with animal organisms. The fact has been already noticed by Ehrenberg.*

The hard Chalk of the North of Ireland also abounds in Polythalamia, though they cannot be separated from the consolidated matrix; but when splinters are broken off, the contour of the shells is marked by translucent lines in the opaque stone, showing that they once existed there as abundantly as in the English Chalk. The consolidation of the stratum from contact with erupted rocks, has obviously altered the appearance of the minute fragments, which, in the friable Chalk rocks of Cambridge, look almost like amorphous lime, but which, in the Irish stratum, can no longer be identified as organic atoms; — an interesting example, conducting us to the more solid limestones from whence nearly all traces of microscopic organisms have disappeared.

The latter appears to be the case with part of the Chalk strata of the Lebanon range. Though in some of these Ehrenberg found Foraminifera, I could not detect any traces of them in the cream-coloured limestones of the Gebel Suneen

* Phil. Mag. Lon. and Edin. Vol. xviii. p. 397.

above Beyrout. Nature has here gone a step beyond what she has accomplished in the Irish Chalk, and obliterated not only the fragments, but the perfect Polythalamia, with the exception of a few scattered translucent points, which may be the faint remaining indications of the once organic condition of the whole mass.

The Blue Clay of Speeton, the Yorkshire representative of the Neacomian series, abounds in Polythalamia. From one specimen, not more than $1\frac{1}{2}$ cubic inches in bulk, I obtained examples of at least five species, consisting of two specimens of a small Nodosaria, two of a Marginulina, two of an Oolina, or same genus identical with fig. 71, about forty specimens of a beautiful little Cristellaria, and above one hundred of a curious form of which I have not yet identified the genus. These, along with a few Entomostraca, and small fragments of shell structures, constituted the only calcareous elements of the stratum. I was much interested in receiving from Mr. Harris a Marginulina and a Cristellaria which he had found in the Gault of Folkstone, both of them identical with my Yorkshire species, as well as a third beautiful form which was new to me.

Of the original character of the calcareous rocks below the Chalk, our knowledge is imperfect, owing to the chemical changes they have obviously undergone since their deposition. To a large number of the Oolitic rocks especially, a pisolitic structure has been given which, in all probability, they did not originally possess. This has been illustrated, by Mr. Lyell, in the case of the larger concretions of the Magnesian Limestone,* and there is little doubt but that somewhat similar changes have been produced in the roestones of Bath and Yorkshire, and the pisolites of Carlsbad. The original state of the calcareous matter to which a pisolitic structure has been subsequently given, is not easily ascertained; but if it was in the form of minute organisms, such as have been described, owing to their small size, they would be more rapidly destroyed by chemical agents than the larger structures; what would be sufficient to obliterate the one would produce little visible effect on the other. Hence, in supposing their original existence in these rocks, we are supported by analogy, especially when we remember the close general resemblance between the *larger* fossils in the Coral and Bath Oolites, and those

* Elements of Geol. p. 77.

of the Chalk, as well as of the existing warmer seas, where Polythalamia abound ; whilst we are going in opposition to analogy in having recourse to some mysterious theory of chemical precipitation, —a process which scarcely finds an illustrative parallel in the unaltered strata of either the Cretaceous, Tertiary, or recent eras. Observation also confirms the probability of this, by shewing that similar Foraminifera and other minute organisms do exist amongst the older strata, as well as amongst the more recent ones; these microscopic forms having occasionally escaped the obliterating influences that have caused such an extensive destruction amongst the greater number.

M. Ehrenberg has already discovered Foraminifera in the compact flints of the Jura Limestone, at Cracow. In one or two instances, I have succeeded in detecting the soft animal, closely resembling fig. 29, calcified and enclosed in a pisolitic granule, from the Yorkshire Coralline Oolite, and have also found well-marked evidence of their existence amongst the oolitic granules of the Bath Oolite. Dr. Buckland quotes the discovery of microscopic shells in the Stonesfield slate, by Mr. Darker,* — proof positive that they were once present, and in all probability in great numbers.

Mr. Strickland has published figures and descriptions of two forms of Foraminifera, under the genera Orbis (Lea) and Polymorphina, from the Lias of Wainlode Cliff, in Gloucestershire.† He remarks that the first of these exhibits no concamerations. and, consequently, should perhaps be regarded as a Serpula. Fig. 34, from the Levant, presents an exactly analagous contour, only the latter exhibits large foramina; but I have seen other species from the same deposit scarcely distinguishable from Mr. Strickland's figure.

The beautiful little fossil found by the late Mr. Bowman, in the Mountain limestone of Derbyshire, and named, by Mr. Phillips, Endothyra

* Dr. Buckland on the agency of animalcules in the formation of Limestone. Edin. New Phil. Journal. Vol. 30, p. 44.

† Quarterly Journal of the Geological Society, London. Feb. 1846.

Bowmanii, is unquestionably a Foraminifer, almost identical in its internal structure and the arrangement of its cells, with the Fusulina of the Russian limestones, confirming the discoveries of Messrs. Tennant and Darker of the existence of microscopic shells amongst the Carboniferous deposits.* Dr. Dale Owen met with well characterised Polythalamia in the oolitic portions of the Carboniferous (Penthremite) limestone of Indiana.† Mr. Phillips states that they occur in the Palæozoic limestones of Carrington Park and South Devon,‡ and Sir R. Murchison has recorded the existence of limestones belonging to the uppermost members of the Carboniferous series, which through a vertical extent of at least two hundred feet, are charged with Fusulinæ,—Foraminifera allied to Alveolina. In one part of the deposit are bands of pure white Fusulina limestone, varying in thickness from fifteen inches to five feet.§ Many of the above Palæozoic rocks have likewise obtained some calca-

* Dr. Buckland ut supra, p. 44.

† Silliman's American Journal. Vol. xlvi. No. 2, p. 311.

‡ Phillips' Palæozoic Fossils, p. 153.

§ Murchison's Geol. of Russia in Europe. Vol. I. p. 86-7.

reous matter from the shells of Entomostraca, which are often exceedingly abundant; especially in strata connected with the Carboniferous era.*

From the above series of facts some important general conclusions may be drawn.

As geologists have long been aware, the bed of the Levant consists of an extensive calcareous deposit, now in process of formation, which deposit is known to extend into the Adriatic, and, in all probability, also into the western parts of the great Mediterranean basin. It appears that this deposit consists mainly, if not entirely, of minute forms of organised structures. Some of these are apparently vegetables, belonging to the siliceous group of Diatomaceæ. Some are of still more questionable affinities, as spicula of sponges, and the siliceous cases of organisms considered, by Ehrenberg, to be Infusoria,—Naviculaceæ, Coscinodisci, and Actynocycli; others are undoubtedly animals, as Foramini-

* Why these Entomostraca should so often be referred to as indicating the existence of fresh-water, I am puzzled to understand. They are much more abundant in the sea than in any of our lakes and rivers.

ferous corals, which constitute an important part of the whole; chiefly belonging to Ehrenberg's groups of Textulinaria, Rotalina, Helicosorina, and Plicatilia, associated with which are various species of Flustra and other soft corallines. Co-existing with these in considerable quantities are portions of crustaceans and Echinodermata, various broken shells, and small calcareous granules,—the fragments of separated shell prisms; whilst the only atoms which appear to be inorganic are some siliceous grains, apparently common sand.

Also, that analogous accumulations are taking place in other parts of the world, especially evident in the case of the beaches accumulating on the shores of existing seas; but that in some of these, especially on our own coasts, Foraminifera and other perfect microscopic organisms are less numerous, the preponderance being in favour of broken shells, mixed up with minute crustaceans and fragments of Echinoderms, along with various proportions of inorganic detritus, especially sea sand.

That throughout an extensive range of Tertiary strata we have undoubted proofs that the operation of similar agencies led to their accumulation, and also that similar causes led to the formation of the Cretaceous strata of both Europe and America.

That in the strata below the Chalk the evidences become more obscure, owing, probably, to some extensive metamorphic action that has modified their structure, but that glimpses may occasionally be obtained, indicating the existence of similar phenomena, even as low as the Silurian limestones.

That though in some strata, as in the Chalk, Foraminifera have been the *principal* instruments in effecting these results, in others, sponges, corals, molluscs, Echinoderms, and crustaceans have contributed their quota to the entire mass, and often in much larger proportions than the Foraminifera themselves. This distinction appears to mark the difference between the deposits formed along exposed coasts and those accumulating in the deeper or more sheltered seas; in some instances, as in the Coralline Oolites of Yorkshire, Oxfordshire, Berkshire, and Wilts, we find the remains of vast coral reefs regularly imbedded in the stratified mass, and most probably still occupying the position they did when tenanted by living polypes.

That as regards the siliceous elements of calcareous strata, few recent deposits exist in which there are not some siliceous cases of the organisms, regarded by Ehrenberg as siliceous Infusoria, but that in the majority of instances, grains of sand constitute the only visible form in which silica exists in any abundance. In this state it is found more or less in all.

It is obvious, then, that if any calcareous deposits are now forming, the results of chemical decomposition, they are not in accordance with the ordinary plan followed by nature in the accumulation of calcareous strata either at the present, or during the Tertiary and Cretaceous periods. At the same time, we must not lose sight of the fact, that calcareous deposits *may* be formed under water, the results of chemical action alone. The Travertins of Italy afford sufficient evidence of this; and if similar calcareous springs existed extensively under the waters of any confined ocean, there is no apparent reason why they should not lead to the production of calcareous deposits, such as are found at San Vignome and at San Filippo. The only approach to an appearance of the kind which has come under my notice, in all the specimens of recent sediment which I have examined, was in the mud from Charlestown harbour, U.S. which, as has been already noticed by Dr. Bailey, contains detached rhombohedra of carbonate of lime, so perfect as to leave little doubt but that they are the direct result of some chemical action, and are not derived from the recent destruction of calcareous organisms. I was interested on finding similar crystals amongst Foraminifera, brought up from an Artesian well sunk at Charleston, at a depth of near two hundred feet; so that those in mud may be derived from the older deposit, with which the stream may come in contact in some part of its course. The existence of Foraminifera in the recent esturian mud renders this somewhat probable; but, on the other hand, in the latter instance, the rhombohedra are so much more numerous than the Polythalamia, as compared with their relative proportions in the borings from the Artesian well, that, if they have been so derived, it has been from some portions of the stratum where the crystals were much more abundant than at Charlestown. At the island of Ascension, Mr. Darwin found that the sands on the beach had been consolidated by calcareous matter deposited from the sea water, in which it was held in solution. The calcareous matter also incrusted the rocks of the vicinity.* An analogous agency has doubtless consolidated the hard sandy portions of the Chalk rubble covering the Chalk rocks on the south side of Flamborough Head, on the Yorkshire coast. An instrument that could do so much might do more, and may possibly have produced the crystalline limestone of St. Fe, as well as the white calcareous rocks of the Pampas and the Banda Oriental.

An exceedingly interesting subject for enquiry now suggests itself. In the recent deposit of the Levant, we have generally an admixture of calcareous and siliceous organisms. In some localities the latter are more sparingly distributed than in others; in a few instances they are almost entirely absent. The same admixture occurs in the recent sands from the West Indies; the soft calcareous mud from the bottoms of the lagoons of the coral islands, contain a considerable number of similar siliceous forms;† and corresponding results have been obtained in most of the marine sediments from various parts of the globe, examined by M. Ehrenberg.

* Darwin's Journal, p. 578. First Edition.

† Darwin's Journal. Second Edition, p. 465.

On the other hand, the Infusorial deposits of Bermuda and Virginia are altogether siliceous. Not one calcareous organism exists. The siliceous forms comprehend the majority of those which I have described from the Levant, many of them being not only *similar*, but *specifically identical*, and the manner in which they are grouped together in these distant localities indicates something more than mere accident; indeed we want nothing but the calcareous structures, to render these Miocene strata* perfectly analogous to those now in process of formation both in the Mediterranean and in the West Indian seas. Are these siliceous deposits, so void of any calcareous organisms, still in the condition in which they were originally accumulated? or were they once of a mixed character, like those of the Levant, having been subsequently submitted to some chemical action, which has removed all the calcareous forms, leaving only the siliceous structures to constitute the permanent stratum? I am disposed to adopt the latter opinion, for several reasons:

* Dr. Bailey informs me, that the Virginian deposits belong, beyond doubt, to the Miocene era. That from Bermuda is more doubtful.

1. When the contents of the stomachs of many mollusks are examined, they contain a mixture of calcareous and siliceous organisms. When this is acted upon by Hydrochloric acid (especially in the case of Pecten Maximus, as shewn by Dr. Mantell and Mr. Hamlin Lee) the result is an accumulation so identical with that from Bermuda as to be most readily mistaken for it. The same thing is still more forcibly manifested when Ichaboe guano is treated with boiling Nitric acid, until all the calcareous and phosphatic portions are destroyed,—the discs, spiculæ, and other organisms, then exhibiting the most striking identity with the American strata.

2. Such deposits, in their present condition, stand out as anomalies in the existing order of oceanic phenomena, and have nothing resembling them except the local fresh-water accumulations which occur in various places. Between these, however, no real analogy exists. It must not be forgotten that the Virginian deposits can be traced for above two hundred miles; and, being marine, would most probably be mixed up with such marine products as were likely to occur along so extended a line. The only recorded instance with which I am

acquainted, that exhibits the slightest resemblance, is furnished by M. Ehrenberg, in his examination of materials brought home from the South Pole, by Dr. Hooker. Some pancake ice, obtained in lat. 78°10′ W. long. 162°, when melted, furnished seventy-nine species of organisms, of which only four were calcareous Polythalamia, the remainder being all siliceous.* But even this example, remarkable as it is, does not supply us with any real parallelism. The deposits in question have never yet exhibited a single example of a calcareous organism. In reply to my query, as to whether there were any local geological phenomena incompatible with the view I entertained, Dr. Bailey observes, "There can be little doubt but that the Polythalamia have been removed from our marine tertiary Infusorial beds, by some chemical action, which action has also attacked the large mollusks, so as to leave only the casts of their shells. Wherever the mollusks are preserved, there are the Polythalamia also." This is most confirmatory. We may then safely conceive that an analogous change has been effected in the Bermuda deposit, where also

* Ehrenberg on Microscopic life at the South Pole. Annals Nat. Hist. Vol. xiv.

we have only siliceous organisms. It becomes probable that many of our European Green-sands, and other siliceous strata, however barren of such structures they appear, may have once contained multitudes of calcareous microscopic organisms, some of which have been removed *after* the consolidation of the strata, leaving either hollow casts, or having had the cavities subsequently filled with Silica, as in the case of the shells at Blackdown; in other instances the change may have taken place whilst the deposits were soft, when the siliceous sand would be pressed down into the spaces previously occupied by the animal body, and thus all traces of the organised structure might permanently disappear.

Nature furnishes us with an agent quite equal to the production of such effects as we are at present acquainted with. This is carbonic acid gas, in solution in water. Mr. Lyell has already availed himself of this instrument to account for the subtraction of calcareous matter from imbedded shells, as well as for some of the changes that have taken place in the structure and composition of stratified rocks.* He has also recorded one

* Principles of Geol. Vol. i. p. 318. Second Edition.

instance, near Clermont, where this process is still going on, the lime being partially dissolved and rendered soft,—the quartz alone remaining unattacked.* Carbonated water has, in all probability, produced some of the changes which the calcareous organisms of strata still retaining much carbonate of lime, but without any visible organic structure, have undergone.

The pisolitic structure of many Oolitic rocks has been referred to. It occurs more commonly than is generally imagined. Sir R. I. Murchison found it in extensive Miocene deposits in Southern Russia. Similar appearances are presented by beds of the same age in Styria and Hungary.† It is more or less common amongst all the Oolitic strata, and is seen in the Carboniferous rocks of Indiana, U.S.

On examining thin sections of oolitic limestone from Bristol, Durdham Down, Yorkshire, and Skerry, I found that the granules in these specimens, composed of the well-known concentric layers, were imbedded in a crystalline matrix.

* Principles of Geol. Vol. i. p. 317. Second Edition.

† Annual Address to the Geol. Soc. By Leonard Horner, Esq. 1846: p. 49.

I was able to ascertain, also, that the former had not only been produced, but hardened, prior to the crystallization of the latter; as in many instances the granules were split across with a clean fracture, sometimes a dozen or more of them being so divided in one line, and the broken portions held asunder by the same crystalline structure which separated the perfect granules.

It is easy to conceive, that whilst these strata were in a less consolidated state than at present, they might be charged with water containing carbonic acid gas. This would act as a solvent of the organic atoms of lime until the acid was neutralised, and the fluid saturated with the alkaline carbonate, which would now become obedient to the ordinary laws of aggregation and crystallization; and, on the recurrence of any material change in the electric condition of the whole, the lime might be redeposited at different periods, and in a variety of forms,—amorphous, crystalline, or concretionary, depending upon delicate and inappreciable causes, of the nature of which our knowledge is very imperfect.*

* Most probably these causes are of an electric character,

That springs possessing a solvent power exist, is proved by their prevalence in most limestone districts, producing Travertins and Tufas, but more especially in volcanic regions. These Tufas are apparently formed at the expense of the older calcareous strata. It is also evident that currents charged with solvent gas may pervade individual strata for a long series of ages, and eventually rob them of all their lime, without materially affecting the rocks either above or below. A thin parting of clay may suffice to direct individual currents, and cause them to flow in one direction with amazing constancy for a long time. This is shewn by many mineral springs, and especially by those of Harrogate. In the garden of the Crown Inn, springs respectively charged with sulphuretted hydrogen and iron bubble up clear and sparkling, within a few feet of each other, and have done so for an indefinite period. Similar phenomena exist

acting under various circumstances of heat and pressure, both of which have clearly exercised a powerful modifying influence. The consolidation of the Irish Chalk, as compared with that of England, owing to the superincumbent mass of ancient Trap, is an illustration of these latter modifying causes. The degree of saturation of the calcareous fluid would also have some influence over the result.

on a moor near the same place. The slightest communication between them would make them both of an inky blackness. They apparently derive their mineral contents from different strata, which are being slowly, but surely, robbed of their mineral contents; and thus Tertiary deposits may have been deprived of all their calcareous organisms by a slow and long-continued process, which has left the insoluble siliceous structures alone undestroyed.

It may be objected, that no such explanation as this will apply to those extensive Limestone rocks already alluded to, where the calcareous matter still remains, though with an obviously altered structure. In such cases the lime has not been removed. This does not materially affect the argument. It only shews that a double process of interstitial solution and re-deposition or crystallization has been going on at the same time. However difficult to explain, the fact may be considered certain, as it is capable of the most satisfactory illustration. It is proved by the spines and plates of Echinodermata, found in the Oolitic strata, where, though the atoms of lime still retain the exact form, and exhibit the beautiful reticular structure of the living organism, yet their arrangement and character have been so altered that the spine, when fractured, breaks up, not in the direction of the organization, but along the lines of cleavage, characteristic of calcareous spar, and that nothing is easier than to obtain out of one of these spines a number of perfect rhomboidal crystals, which nevertheless exhibit, under the microscope, all the interesting structure which Dr. Carpenter has shewn to be peculiar to the Echinodermata. Here is obviously an instance of double action. The place of each atom, as it was removed, must have been supplied by another of the same substance, only it has been rendered obedient in its re-deposition to the laws which regulate crystallization, rather than those of organic life. At the same time, why the larger organisms should retain their original structure and contour, whilst the microscopic forms alone are replaced by pisolites, roestones, and crystalline limestones, is a question that I am unable fully to answer. Analogous phenomena, however, exist elsewhere, which shew that an extensive metamorphic action, either chemical or volcanic, sufficiently powerful to destroy all the smaller organisms, does not of necessity affect the integrity of the larger fossils. Sir R. I. Murchison has recently shewn us that very extensive changes may be effected in the atomic structure of calcareous rocks, and, consequently, in all the microscopic organisms not materially larger than the amorphous atoms of the rocks, without involving the destruction of their fossils. He has given an interesting example of this in the little oasis of fossiliferous Carboniferous limestone at Cossatchi Datchi in the neighbourhood of the Ural, where a patch of limestone surrounded by eruptive rocks has been thrown up into calcareous hummocks, an appearance compared by the author to the hornitos of the Mexican Jorullo. This effect Sir R. I. Murchison ascribes to heat and gaseous vapours which formerly struggled for expansion, and which have obliterated all lines of stratification, and rendered the limestone as pulverulent as sugar ; yet it abounded in interesting fossils.* In the valley of the Miass also he found Encrinites in a pure saccharoid limestone, which had also been highly altered by neighbouring, eruptive works.† These instances prove how large an amount of change may be wrought in the atoms of a rock by gases, under the influence of volcanic heat, without obliterating its larger

* Geol. of Russia in Europe. Vol. i. p. 439.

† Idem, p. 426.

fossils; still more easily can we conceive of water containing carbonic acid slowly destroying the smaller organizations of a Foraminiferous limestone without producing any very great effect on the larger structures. The solvent would act upon the surfaces of the large and small fossils with equal rapidity; but what would obliterate a Foraminifer, the two or three hundredth part of an inch in diameter, would produce but little change on the surface of a thick shell.

There are still many difficulties to be encountered in the settlement of this great question. There is no doubt but that some strata, even of recent date, which contain multitudes of Foraminifera and other small organisms, both entire and in fragments, also contain large quantities of amorphous calcareous matter which cannot be *directly* traced to any such origin. The chalk from the Missouri has been already alluded to as of this character. It is not impossible that the opaque portions of the Missouri chalk may in reality be the exuviæ of the lower animals; and that the latter may have been the instruments of an extensive conversion of lime from an organized to an amorphous form. In the above instance it is obvious that no external agents, acting generally upon the whole mass, can have produced the change from a transparent and organized to an opaque and inorganic condition, or all the fragments of the minute Foraminifera would have been more or less affected in the same manner. But such is not the case. The latter retain their vitreous transparent aspect; hence the amorphous part of this deposit must either have been derived from some other source than broken Foraminifera and analogous minute structures, or it must have been altered by some agency acting only upon *some* of the atoms now constituting the stratified mass. The digestive organs of molluscous, acephalous, and other marine animals appear to be the only instruments which would be likely to effect such results. We have the *copros* of saurians and of fish constituting extensive stratified layers,—why, then, should we not have the *excreta* of molluscs and other inferior animals? Mr. Darwin met with two species of fish in the neighbourhood of Keeling Island belonging to the genus Sparus, which feed entirely on coral. On opening their intestines, he observed them to be distended with yellowish calcareous matter; and he adds:— "These fish, together with the lithophagous shells and Nereidous animals, which perforate every block of dead coral, must be very efficient agents in producing the finest kind of mud; and this, when derived from such materials, appears to be the same with Chalk."* May not much of the amorphous calcareous matter which occurs in the Coralline Oolite of Yorkshire have been treated in this way? Lithophagi are abundant in the deposit; Modiola inclusa is still fixed in the hard corals into which it had bored; whilst the rounded and enamelled teeth of the Malton fish are such as would be well adapted to crushing calcăreous organisms.

If a few soft fluviatile Infusoria are put into clear water, with nothing to feed upon except beings like themselves, it is surprising what an amount of their exuvia is accumulated in a few days. If we allow a similar process to go on amongst larger animals only feeding upon small calcareous creatures, instead of the soft tissues of Infusoria, we may readily conceive that in the space of hundreds of years an enormous amount of amorphous calcareous matter would be accumulated. Even those animals which are phytophagous must contribute to this, for they cannot feed upon a single marine plant without

* Darwin's Journal. 1st Edition, p. 553.

devouring multitudes of the calcareous Polythalamia, Escharæ, and other parasitic corals, with which most marine Algæ are loaded.

Something analogous to this has taken place at the time of the accumulation of the guanos of Ichaboe and Peru. It is obvious that all the vast multitudes of siliceous Infusoria which they contain have been taken up by the birds whilst in the stomachs of molluscs and other soft animals. That the latter feed largely upon them is abundantly proved; and when we remember with what a formidable rasping apparatus the palates of many of these creatures are armed, we shall cease to wonder that they can grind either calcareous or siliceous structures to powder. Amongst the Russian Fusulina limestones already noticed, I mentioned that portions of the series exhibited bands from fifteen inches to four or five feet thick, consisting entirely of Fusulinæ; but above and below these the Polythalamia diminish in number until at length only a few specimens are found, along with other fossils, scattered through the limestone. In the latter instance it is evident that, in addition to what has been contributed by the calcareous cases of the Fusulinæ, there has been, as in the example of the Missouri Chalk, a considerable amount of calcareous matter derived from some other source than the mere breaking up of the Foraminifera, and the metamorphic condition of which has been produced without destroying the contour of the latter small animals. How far may calcareous excretions have existed here? At the same time, such strata as the limestone of Santa Fé and the white calcareous marl of the Pampas seem to indicate, in addition to organic causes, either chemical deposition or the extensive instrumentality of some agency that has altered the appearances of the rocks subsequent to their deposition.

The strata of Magnesian limestone and crystalline Dolomites, present new difficulties in the way of accounting for the origin of *all* calcareous rocks by the operation of vital causes. They contain various proportions of magnesia and lime, amounting, in many instances, to as much as 45.82 per cent of the former, to 54.18 of the latter.* Now, no organisms that I am acquainted with would have separated these two earths from their state of solution in the sea-water, in anything like the above proportions. Even the bones of

* Rammelsberg, Handwörterbuch der Mineralogie.

animals do not contain above 1 per cent of phosphate of magnesia, to about 62 of carbonate of lime. I am not aware that shells and microscopic organisms contain any appreciable quantity. Hence it is clear, that in the case of Dolomites, there must have been in operation other causes than those dwelt upon in the preceding pages, which have separated the magnesia from the water, and precipitated it in an insoluble form. The chemical agents which would accomplish this, would produce the same effect on solutions of lime; and hence, as sea-water contains both, and there is every reason to believe that the magnesia was so thrown down, it almost renders it certain that lime has, in some cases, also been a chemical precipitate.

Another question closely allied to the preceding is,—From what source have the flints and cherts of Chalk and limestone been derived? It is well known that almost every calcareous deposit contains more or less of siliceous matter in some form or other, but most frequently aggregated either as nodules, or concretions, or horizontal layers. Ehrenberg remarks,—"In the south of Europe, the beds of marl which alternate with the Chalk, consist of siliceous shells of Infusoria, and flints are wanting; while, in the North of Europe, beds of flint alternate with the Chalk, and marls with Infusoria are wanting. This exchange of character tends to explain the peculiar relation of flint to Chalk, indicating that the pulverulent siliceous particles of Infusoria have been converted into compact nodules of Flint."*

But there are reasons for believing that the great facts upon which this hypothesis is based, are incorrectly interpreted, and that no siliceous Infusoria belonging to the Cretaceous era have yet been discovered. The great siliceous deposits of Virginia belong unquestionably to the Miocene epoch. Those brought by Mr. Darwin from Patagonia, form part of a recent Tertiary deposit, and there is every probability that the Infusorial layers of Sicily and Northern Africa will ultimately be proved to belong to the Tertiary era. I am not aware that any observer has succeeded in verifying the alleged discovery of siliceous Infusoria in the English Chalk, and the American rocks which are unquestionably Cretaceous, have as yet been equally unproductive. If these facts be correct, of course the argument raised by

* Phil. Mag. Vol. xviii. p. 385.

Ehrenberg is done away with, so far as it is based upon the alleged absence of flint from Infusorial strata, and their presence where such Infusoria are wanting. At the same time, this does not prove that siliceous organisms *may not* have been separated from the calcareous elements of a rock, and subsequently brought together again in a new form, constituting flint. If anything of this kind has taken place, it could only have been by the introduction of some agent capable of dissolving the siliceous base of these structures, and any such agent would of course also act upon the siliceous sand grains, which occur more or less abundantly in every calcareous stratum; consequently, if the Flint has really been derived from the stratum itself, since sand grains are so much more abundantly diffused than Infusoria, or sponge spicula, even in the substance of the Flamborough sponges, it is more likely that the inorganic elements have been the usual source rather than the organic, though of course both would combine to produce the result.

It is, however, more probable, that the Silica has been derived from largely saturated hot springs, as advocated by Dr. Mantell in his "Notes on the Chalk and Flint of the south east of England,"* and that whilst it has invested some objects, it has filled the cavities of others, and shewn a manifest preference for combining with, and replacing animal substances. This, however, is as yet a very obscure and difficult subject; one that must probably be treated very differently according to the strata we may be examining.

In some cases, as in the examples of silicified fossil woods, the flint appears to have been deposited atom by atom, since, though the carbon is replaced by silica, all the original microscopic structure appears to be preserved. At the same time, all the interstices and fissures in the wood are often filled up by clear chalcedony, which bears every appearance of having run into the fissures in a fluid state.

At other times the original elements of the organism have been wholly or partially removed, leaving a cavity, which has been filled up by infiltration of siliceous matter, subsequent probably to the consolidation of the rock; the interior of such organisms, when the filling up has not

* Annals and Mag. Nat. Hist. August, 1845.

been completed, exhibiting either a crystalline and quartzose, or the botryoidal aspect so common to the Chalcedonies deposited by the Geysers. In neither of these is any trace of the original structure of the shell preserved, and I cannot but think that the removal of the lime has in such cases been rendered more or less complete before the introduction of the silica; consequently, instead of being deposited in such a way as to preserve the original structure, atom replacing atom, the cavities are more or less perfectly filled with crystalline chalcedony, according apparently to the duration of the process, and the size of the cavity; the smaller organisms being in general completely solid, whilst the larger ones are merely lined with the siliceous matter. Similar phenomena occur amongst the silicified organisms of the harder portions of the Calcareous Grit in Yorkshire.

What has taken place in the flints of the Chalk? This is difficult to answer, as we have evidence of a much more complicated agency. I have already remarked, that the Rotaliæ from the chalky surfaces of flints, though unattached to the flint itself, are nevertheless often changed into silica, and it would appear that the Rotaliæ embedded in the solid flint have also become silicified; but the silica replacing the calcareous cells has a more transparent aspect than that surrounding and filling them, as if the organism had been first silicified, and then invested with flint of a less transparent character. Moreover, some of these Rotaliæ clearly retain part of their original animal matter, apparently in the condition of Molluskite, as advocated by Dr. Mantell. I have already spoken of my instructive specimen from Flamborough Head. The outer calcareous part is silicified, its outline being comparatively distinct, as contrasted with the darker investing flint. The animal portion has shrunk up within the shell into a smaller compass, still preserving its original brown hue, and affording an almost exact representation, both as to colour and form, of the animal from the Levant (Fig. 29). In this case I can see no room for doubting that at least the colouring matter of the animal membrane is preserved; and, as in such a texture as this it would be difficult to divide the latter from the former, what ground is there for doubting that the animal membrane is itself present either in the state of Molluskite, or in such close and intimate union with the siliceous matter as to be justly regarded as a silicified animal? This is clearly no cast of the interior of the shell, filled up with a differently coloured flint from that by which it is invested. The wide interval between the walls of each cell and the shrunken animal, which interval is occupied by transparent flint, like that outside the whole, seems to remove all possibility of doubt. The Levant specimen shews that the animal part of a Rotalia may be occasionally deprived of its calcareous covering, and yet be preserved, illustrating those instances which sometimes occur where this portion alone is found in a fossil state. If any number of living Foraminifera happened to have accumulated at a point where a volcanic spring charged with any solvent acid subsequently burst out, such results would be readily produced.

Some of the conclusions at which Ehrenberg arrived, resulting from his investigations into the composition of Chalk and Chalk marl, require to be received with great caution, as the facts upon which they are based are scarcely sufficient to support them. One of these is, that "many of the chalk-like formations bordering on the Mediterranean, in Sicily, Barbary, and Greece, really belong to the Chalk formation, as proved by their organic contents, although commonly held to be different from the Chalk, and considered as Tertiary."* This conclusion appears to have been arrived at by Ehrenberg in consequence of finding certain organisms in them which occur in the Chalk; but the evidence afforded by the higher forms of Testacea and other animal remains, distinctly separates them. Now, a close investigation of the history of the Polythalamia, Diatomaceæ, and siliceous Infusoria, so-called, will bring us to the conclusion, that but little, if any, dependence can be placed on them, as a means of identifying either the age or the geological position of rocks. Beyond all doubt there exists in nature a number of minute structures, cosmopolites, which appear to be comparatively independent of the ordinary influences of locality and climate. The fresh-water pools of America, England, and Central Europe, contain not only identical forms of Desmideæ, Diatomaceæ, and Spongillæ, but there is a closeness of resemblance in the aggregation of their species which we do not usually observe in the distribution of the higher forms of plants or animals. Dr. Bailey has discovered few forms in the United States that have not also been found by Mr. Ralfs and his active coadjutors in England, whilst most of the leading species observed by the

* Phil. Mag. Vol. xviii. p. 385.

latter, have also been found by Ehrenberg in Central Europe.

If we turn to the ocean, we meet with corresponding results. Amongst the siliceous structures, the Actinocycli and Coscinodisci found in the stomachs of crabs from the west coast of Scotland, of muscles from Scarborough, and of Pectens from Brighton, occur equally in the waters of the Baltic, in the sediments of the Mediterranean, and in the guanos of Ichaboe, and Peru. Biddulphia pulchella has been found on our own coasts, in the Mediterranean, on the shores of Long Island U.S. at the Phillippine Islands, and at Cuba.

The Foraminifera bring us to analogous conclusions. Globigerina bulloides is found on both the coasts of America, at the Canary Islands, in the Mediterranean, and in the Indian Sea.* Bulimia elegantissima ranges from Patagonia to the coasts of Chili and Peru.† Four other species are common to Cape Horn and the Malvinas.‡ M. D'Orbigny adds, "when we unite together the

* Alcide D'Orbigny on the Foraminifera of America and the Canary Islands. Edin. New Phil. Journal. Vol. xxxii. p. 6.

† Idem, p. 11. ‡ Idem.

species of Arica and Callao, the harbour of Lima, that is from 12° to 15° S. lat., in order to compare them with those of 34° S., we have fourteen, of which four extend northwards as far as Paita and to the equator."* The same writer also tells us, that seven species of the Foraminifera, found at the Canaries, are also common to the southern and western coasts of France. One of them, the Truncatulina lobata, also occurs in the British seas and at the North Pole.

If, then, there is amongst these little creatures such an independence of climate and other outward conditions, the same thing would naturally influence their geological relations. They would survive catastrophes which were fatal to the higher organisms, and thus we might expect, *a priori*, to find individual species ranging through a number of strata, and during a comparatively long geological period, without affecting the great fundamental views which geologists hold as to the geological distribution and the periodic destruction of most living existences. Such is precisely what we have the authority of M. Ehrenberg himself for believing to occur;—

* Idem, p. 11.

Rotalia globulosa, R. turgida, Textillaria aciculata, and T. globulosa, the characteristic Foraminifera of the Chalk of England, having all been found living in the North Sea, at Cuxhaven. This alone is sufficient to show the impropriety of trusting to them as a means of identifying the age and geological position of any deposit.

The same line of argument applies equally to another of M. Ehrenberg's views. He says,— "The idea that the temperature and constitution of the atmosphere and ocean were essentially different at the period of the Chalk formation, and adverse to the organized beings at present existing, naturally acquired more probability and weight, the more decidedly different all the creatures of that period are from those of the present time; but loses more and more in importance, the less Chalk proves to be a chemical precipitate, and the more numerous the forms, agreeing with those of the present day, become by renewed enquiry. Nay, there is not the least doubt that the perfectly ascertained identity of a single species of the present day, with one of those of the Chalk, renders doubtful the necessary transformation of all the others, subsequently to the formation of the

Chalk rocks. How much more so when these are numerous, and such as form large masses. The size appears to be of no importance, as the small organisms have already been shewn to agree with the large, with regard to the effect of external influences upon them."*

As regards the higher animals, the first part of this paragraph is doubtless correct; but the force of the argument is weakened, if not destroyed, when it is applied to the Foraminifera and other microscopic creatures. The small organisms do *not* agree with the large, with regard to the effect of external influences upon them. With reference to climate, enough has been said to prove, that they neither follow parallels of latitude, nor isothermal lines; and as regards another condition, Professor Forbes has shewn that Foraminifera occur in the sea, at a depth of one hundred fathoms, when the higher forms of animals and plants cease to exist;† also, Alcide D'Orbigny informs us, that, opposite Cape Horn, at a depth of one hundred and sixty metres, (about eighty-seven fathoms,) the

* Edin. New Phil. Journal. Vol. xxxiv. p. 258.

† On the Light thrown on Geology by Sub-marine Researches. Edin. New Phil. Journal. Vol. xxxvi. p. 319.

bottom of the sea only furnished an abundance of Foraminifera. These facts indicate important differences in the effect of external influences, and at least show that the evidence afforded by the Foraminifera, must not be allowed to outweigh that furnished by the higher plants and animals, which are so much more sensitive to changes of latitude, climate, and depths of ocean. This is all consistent with what we know of the low sensibility of even those higher forms of Infusorial animals, such as the Rotifera, which, Dr. Carpenter tells us, may be frozen up in ice and thawed again for a succession of times without life being destroyed. The Foraminifera, it must be remembered, have a much less complicated organization, and hold a lower position in the scale of animal life than the Rotifera, and, consequently, might be expected to be still less under the influence of external agents.

More recently M. Ehrenberg appears to have altered his opinion on some of these points. In a recent work* he remarks, "As a considerable number of the species of animals belonging to the

* Verbreitung und. Einfluss des Mikroskopischen Lebens in Sud und Nord America.

Chalk formation of Sicily still exist, and, consequently, cannot be wanting in the Tertiary formations, it is evident that no conclusion, as to the geological age of these formations, can be drawn from the similarity or dissimilarity of these forms."*

This paragraph annuls much of M. Ehrenberg's previous argument; but as the latter has been far more widely circulated in England than the former, it is desirable that every opportunity of correcting the error should be made available for that purpose, and more especially as M. D'Orbigny still appears to hold some similar views, notwithstanding the numerous opposing facts which he has himself brought to light.† Speaking of the study of the Foraminifera, as applied to geology, he remarks, that "as these minute shells are infinitely more common than those of molluscs, the knowledge to be derived from them is so much the more certain, and becomes extremely interesting." And again, after stating his opinion, that different terrestrial zones have their peculiar species, he

* Silliman's American Journal of Science. Vol. xlvi. p. 297.

† Mr. Weaver's Abstract of the Memoir of M. Alcide D'Orbigny, on the Foraminifera of the White Chalk of the Paris Basin. Phil. Mag. Vol. xviii. p. 456.

adds, "Hence, the geographical distribution of living genera and species offers to us a means of comparison of the highest importance, with a view to the determination of the temperature of the waters in which the fossil species lived, and may lead to very satisfactory results in geology, if we may judge by the fruits of our observations in this respect."*

These conclusions require to be received with the utmost caution, if the study of the Foraminifera is to be made of any real use in the attainment of new geological truths. Our knowledge of these singular creatures is as yet much too elementary, for us to come with safety to any very general conclusions. M. D'Orbigny's paper, from which the above is quoted, is an evidence of this. After advancing various arguments to prove that the temperature of the great basin in which the Chalk of Europe was deposited, was analogous to that of the Adriatic at the present time, he adds, "To complete the approximation, it (the Adriatic) exhibits to us the only two living species, the analogues of which are found in the fossil state in the white Chalk, viz. Denta-

* See preceding Note. Mr. Weaver's Abstract, p. 457.

lina communis, and Rotalina umbilicata."* The same volume which contains this remark, also contains the opposing observation of M. Ehrenberg,—that, of the Foraminifera found in the white Chalk, *nine* still exist, of which *six* occur *in the North Sea, at Cuxhaven ;* four of the six being found in the white Chalk of England, which M. D'Orbigny distinctly includes in his supposed analogy to the Adriatic. On seeking for the analogues of the beautiful little fossils from the Charing chalk, I found examples of either several of the species, or of others exhibiting the closest resemblance to them, in the cabinet of Mr. Bean, at Scarborough, who chiefly obtained them from various localities on the Scotch coast. At the same time, many recent and fossil species bear so close an external resemblance to each other, that it is a most difficult thing to decide with absolute certainty which are and which are not distinct. Some of our best observers in England doubt, for instance, the identity of M. D'Orbigny's Dentalina from the Chalk and the recent D. communis ; yet this is one of the species upon which that most acute observer builds his hypothesis.

* Idem. p. 462.

How cautious must we then be in advancing any conclusions relating to temperature and climate, as well as to the geological age of rocks from such comparatively uncertain data. To use the language of a distinguished writer, in his well-merited criticism of a very different work from any of these which have rendered so illustrious the names of Ehrenberg and D'Orbigny, "We may explain the obscure cases of nature's work by appealing to the clear—but do not let us stultify what is clear, by starting with the obscure."* So, in like manner, we must not cloud the evidence afforded by the higher animals, with that derivable from beings so much lower in the scale of organization, and which, as a whole, are so far removed from the influence of external agencies. The study is at once so novel and so fascinating, that all who pursue it, impressed by its singular interest, are in danger of being allured by it beyond the bounds of caution,—a tendency which is ever promoted by the announcement of comprehensive hypotheses and splendid novelties.

* Review of the Vestiges of the Natural History of Creation. Edin. Review, No. 165, p. 65.

I cannot close this memoir, without once more drawing the attention of the Society to the important part which the minute and singular beings now brought under our notice, play in the economy of the physical world. If we look into the ditches and pools of our immediate neighbourhood, we find them teeming with some form or other of these microscopic structures. The superficial mud of our rivers, lakes, and estuaries, is alike vital with their swarming millions. The waves of the ocean, when glittering with phosphorescent splendour, indicate that, however pure and transparent they may appear to the unassisted vision, they are loaded with similar forms of organic life. From the stormy seas of the Northern Pole to the wild and desolate shores of Mount Erebus,* these atoms of creation exist in all their variety of structure, and wondrous diversity of movement. They form some of the earliest instruments by which inorganic elements are transmuted into an organized condition. They constitute the pabulum of myriads of those bulkier creatures which, though of so much more apparent importance, could be better spared without deranging

* Ehrenberg, on Microscopic Life in the Ocean at the S. Pole. Annals Nat. Hist. No. 90, p. 169.

the physical economy of the world. Abounding at almost every point, they act as nature's universal scavengers, taking up those decomposing substances which would otherwise fill our waters with impurity, and our atmosphere with the elements of disease.

Our feeling of wonder, however, reaches its climax when we are informed that even many of "the everlasting hills" owe their origin to such pigmy architects of nature; enduring monuments of the mighty results that may ensue, from the long-continued action of causes the most minute and inappreciable. It is gratifying to find so clearly written in this, one of the last opened pages of nature's volume, a truth which in the moral world, is everywhere proclaimed; a truth that should inspire the mind, not only with wonder, but with humility and adoration.

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