On the Age of the Coal Rocks of Eastern Virginia. By William B. Rogers, *Professor of Natural Philosophy in the University of Virginia.*

The formation here referred to, overspreads parts of Chesterfield, Powhatan, Amelia, Henrico, Hanover, and Goochland counties, lying in basins of granite and gneiss, the principal coal seams being separated by only a few feet, and sometimes by but a few inches, of carbonaceous shale from the floor of primary rock. In some places near the eastern margin of the field, where it has been most extensively explored, the thickness of this group of strata is about eight hundred feet, but towards the centre of the principal basin it is probably somewhat greater. Throughout much of this depth the strata consist of coarse grits, composed of the materials of granite, so little worn as to have the aspect of this rock in a decomposing state. The coal, which in the northern parts of the field is divided into two and sometimes three distinct seams, separated by considerable intervals of slates and grits, but all comprised within the lowest one hundred and fifty feet of the series, is in the more productive region, south of the James river in Chesterfield county, collected together into one immense stratum, which, though of very variable thickness, may be generally stated at from twenty to forty feet.*

The curious circumstance, of the grits and coal-bearing strata of this region resting immediately on a floor of granitic and gneissoid rock, appears early to have attracted notice, and, connected with the fact, that the coarser sandstones are but the recemented materials of the adjoining primary masses, almost unmarked by aqueous wearing, seems to have led to the prevailing belief of the very high geological antiquity of these deposits. Such considerations, and others, chiefly lithological, would appear to have formed the grounds upon which the distinguished pioneer

* For a particular account of the boundaries and contents of this coal field, the composition of its numerous varieties of coal, and other details, see Reports of Geological Survey of Virginia, for 1836, 1840. Also, "Memoir of a Section passing through the Bituminous Coal Field near Richmond," by Richard C. Taylor. A more copious and accurate account will hereafter appear in the Final Report on the Geology of the State.

of American Geology, Maclure, founded his reference of this remarkable series of grits and carbonaceous strata, to the period of the old red sandstone. More recently, Mr. R. C. Taylor, in an interesting paper relating to this region, in the Transactions of the Geological Society of Pennsylvania, expresses himself as "rather inclined to assign this independent coal formation to the transition carboniferous deposits, than to the secondary class," on the ground of the absence of any "analogy" between it and the latter, "throughout the whole series of superincumbent strata."

The further explorations in this region, made in the course of the Geological Survey of the State, aided by new and extended mining operations, having brought to light, more clearly than before, many interesting organic remains, chiefly of vegetable origin, have afforded me the opportunity of accumulating important data for determining the epoch of this isolated and remarkable coal formation. In the absence of such a guide, and judging by lithological indications alone, perhaps no more probable conclusion would have been reached on this subject, than that of the able geologists whose names have just been mentioned.

These vegetable remains, *as a group*, bear a striking resemblance to those which accompany the Öolite coal of Brora, Whitby, and other European localities. Some of them, as, *Equisetum columnare*, *Calamites arenaceus*, *Pecopteris Whitbiensis*, *Pecopteris Munsteriana* and *Lycopodites uncifolius*, are, I think, specifically the same with the European fossils, while the rest, among which are *Tæniopteris magnifolia*, an unnamed *Pecopteris*, and two or perhaps three species of *Zamites*, are very closely allied to certain species of the same genera, found in connection with the Öolite coal of Yorkshire, Sunderlandshire, and other places in Europe.

The most abundant of these remains are, the *Equisetum columnare*, also said to exist in great profusion at Brora and Whitby; a large species of *Zamites?* hereafter to be noticed; and a magnificent *Tæniopteris*, (*T. magnifolia*,) very closely analogous to *T. vittata* and *T. scitaminea* of the Yorkshire and Sunderlandshire formation. These four being found in vast numbers immediately upon, and interlaminated with the coal, where it is slaty, would appear to have furnished the principal materials of the stratum. No remains bearing any resemblance to *Stigmaria* have been discovered either in the soft carbonaceous slates beneath, above, or in the midst of the seams, or in the other slaty and gritty strata of the series.

With such a striking agreement, as regards not only the general character of the vegetation, but the individual plants belonging to the rocks now under consideration, and those of the Öolite coal of Europe, it can scarcely be doubted that they were formed during the same or very nearly the same geological period, and I therefore feel no hesitation in referring the *coal of Eastern Virginia* to a place in the *Öolite system on the same general parallel with the carbonaceous beds of Whitby and Brora*—that is, in the lower part of the Öolite group.

This determination possesses, I conceive, no small degree of interest in its connection with our geology generally, inasmuch as it supplies a very important link in the great geological succession of formations, which had not previously been discovered anywhere within the United States. Nor is its importance less, when connected with the striking discovery of Capt. Grant, of an Öolite coal-series in the opposite hemisphere, near the mouth of the Indus, some of the fossils of which appear to be almost identical with plants, from the Virginia coal rocks, hereafter to be described.* With these discoveries in view, it can scarcely be doubted that the *fossil flora* of even the *middle geological periods* has sufficient uniformity of character, even in opposite parts of the globe, to furnish a very useful guide in the comparison and identification of great geological groups.

Of *Animal remains*, so abundant in the Öolite generally, the only traces yet discovered in the Öolite coal series of Virginia consist of *teeth*, apparently *Saurian*, recently found by me in and a little above one of the coal seams in the northern part of the district, and the scales and sometimes entire impressions of a slightly *Heterocercal* fish, referred to, doubtingly, by Mr. Nuttall,†

* See "Memoir to illustrate a Geological Map of Cutch." By C. W. Grant, Esq., Trans. Geol. Soc. Lond., Vol. V., 2d series.

† See Trans. Acad. Nat. Sciences, Philadelphia. Vol. 2.

many years ago, and lately examined and named by our able icthyologist, Mr. Redfield.

The coarser rocks, lying above the carbonaceous strata, and forming the greater part of the thickness of the series, contain very few organic remains, and those in so imperfect a condition as to have little or no value for purposes of comparison. There are, however, strong reasons for believing that these strata, by a gradual transition, pass upwards into the series of felspathic sandstones, described in my Report of the Geological Survey of Virginia for 1840, under the title of *Upper Secondary Strata.* The latter, considered by Messrs. Taylor and Clemson, as "of secondary origin, perhaps coeval with the Öolites," have since been referred by myself and Prof. H. D. Rogers, to the *upper part* of the Öolite series, so that this great division of the geological column, though still perhaps very imperfectly represented in the United States, comprises a thickness of considerably more than one thousand feet of strata.

I may here incidentally remark, that certain fossils (*Posidonomya Keuperi? &c.*) which I have recently found in a particular division of the new red sandstone (*Middle secondary*) of Virginia, have led me to infer the existence in that formation, of beds corresponding to the *Keuper* of Europe. A more particular account of this discovery is reserved for a future occasion.

The following descriptions of some of the principal fossil plants, found in connection with the Öolite coal of Eastern Virginia, are the results of a careful comparison of the specimens with the figures and descriptions of analogous fossils, in Sternberg, Brongniart, Bronn, Lindley and Hutton, Phillips, and the Memoirs of Murchison, Grant, and others relating to the subject. These, with others not yet ready for the press, will, I trust, fully sustain my conclusion as to the age of the remarkable coal-formation under consideration.

The details which they include, though inconsistent with the elegance of technical description, together with Plates XIII and XIV, will, it is believed, facilitate a just comparison of these fossils with those of the Öolite coal-formation elsewhere.

Fossil Plants of the Öolite Coal Rocks of Eastern Virginia.

Equisetum columnare. *Brongn.*

Oncylogonatum carbonarium. Koenig.
Equisetites columnaris. Sternberg.

The fossil referred to under this title, occurs very abundantly in certain slaty and argillaceous rocks met with at nearly all the openings in the coal-fields, both north and south of the James river, and appears to have formed one of the chief sources of the material of the coal beds. The specimens in the slaty rock are generally flattened out parallel with the laminæ of the slate, and from the conversion of the vegetable matter into coal, give rise to alternations of coal and slaty material, sometimes as numerous as thirty in an inch. On one of these masses of slate in my collection, there is a beautiful impression of a part of the *Equisetum*, about fifteen inches long, and where widest, seven inches broad, comprising ten distinct articulations, the intervals of which regularly diminish from one extremity of the fossil to the other. Specimens of this fossil are also met with in a dark bituminous clay, and a light brownish, soft sandstone, both of which occupy a place near the coal. In these the rotundity of the stems is pretty well preserved, the rocks imbedding them being destitute of the laminated structure.

The flattened as well as the convex impressions agree exactly with the figures appended to Murchison's Memoir on the coal field of Brora, Trans. Geol. Soc. of Lond., Vol. II, Part II, and correspond in every particular with the description of the Brora fossil as given by Koenig in this memoir. The "acute regular furrows of various lengths, gradually diminishing in width, and running out into linear grooves," and "the elevated rays or ribs having a pretty acute ridge, and gradually tapering into a fine, more or less lengthened raised line," referred to by Koenig, as impressions produced by the flattened stem of the *Oncylogonatum*, and represented in figures 3 and 4, of Mr. Murchison's Memoir, are facsimiles of the Virginia fossil, as it occurs in innumerable layers in the slaty rocks, or is impressed on the parting surfaces of some varieties of the coal. Nor is the resemblance less perfect between the uncompressed form of the Brora fossil as represented in figures 1 and 2 of the Memoir, and the cylindrical jointed stems marked near the joints with similar grooves and ribs, already alluded to as occurring in certain soft sandstones and argillaceous beds in the Virginia localities. I have therefore no hesitation in considering the Virginia fossil as identical with that of Brora, as well as with that referred to by Prof. Phillips in his Geology of Yorkshire, as occurring in the sandstone at High Whitby, and recognized by him to be the Brora fossil. Guided by the authority of Brongniart, who describes specimens from Brora, Whitby, and other European localities, I shall hereafter speak of our fossil as the *Equisetum columnare*.

In all the British localities of this fossil, as Whitby, Haiburne, Wyke, and Brora, it occurs in connection with carbonaceous beds, appertaining to the *Lower Öolite*. In the neighborhood of Balbronn, Gemonvel, Studtgard, and other localities on the Continent, it is found in geological connections less certainly determined, but which Brongniart infers to be the same as those in which it occurs in Great Britain. In closing his account of this fossil, Brongniart says: "In England, where the secondary formations have been so well studied, no trace of this plant has yet been found in the lias, or in the more ancient beds, or in the Oxford clay and more recent formations; nor does any thing in the Stonesfield limestone or Tilgate limestone, indicate the presence of this plant, *which we may therefore consider as characterizing the lower beds of the Jura limestone*" (*the Lower Öolite*).

Equisetum arundiniforme.

The fossil for which the above title is provisionally proposed, bears a close resemblance to the stem of a common reed, bruised and flattened by pressure. The most perfect specimen in my possession is on a light gray, slightly micaceous slate. The stem, which is flattened out, is fifteen inches long, and two and a half to three inches wide, divided by joints about four inches asunder.

The surface, though entirely destitute of regular ribs or striæ, is marked, especially in the vicinity of the joints, with low, short, triangular plicatures, apparently due to compressing action. At the joints, which are beautifully distinct, and over much of the surface, the slaty matter is covered with a siliceous coating of a lighter color and much greater hardness than the body of the rock, derived apparently from the joints and epidermis of the plant.

The lower and toothless joint, in Plate XXXI, fig. 3, Sternberg, representing *Equisetites acutus*, bears a strong resemblance to this fossil, as do also the reed-like stems represented along with impressions of *Zamites heterophyllus*, in Plate XLIII, figs. 4 and 5, Sternberg.

Calamites arenaceus. *Brongn.*

The fossil referred to by this title is frequently met with in the coal rocks of Eastern Virginia, occurring both in the dark laminated slates, and in the soft, bluish-gray sandstones. In the former position it is generally very much flattened, from compression between the layers of slate; in the latter it is often quite cylindrical, being found in an erect posture in the rock.

On comparing some good specimens in my collection with Brongniart's figures and description of *C. arenaceus*, I am convinced that our fossil is of this species, or one very closely allied to it, and that it differs in many important points from *C. Suckowii.* The calamite from Eastern Virginia, forwarded by Prof. Silliman to M. Brongniart, and by the latter figured as *C. Suckowii* was obviously, and as he himself confesses, a very imperfect one, and as will be seen by inspecting his drawings, differs in many respects from the other specimens, referred by him to the same species, all of which were derived from the true carboniferous formation. From Brongniart's drawing of the Virginia specimen, and his statement that it is nearly or entirely *destitute of tubercles* at the joints, in which it strikingly differs from the true *C. Suckowii*, and agrees with the *arenaceus*, I am fully convinced that the fossil figured by him as a variety of *C.*

Suckowii, is the same as that I am now describing, and is the true *Calamites arenaceus.*

It may, perhaps, be conjectured, without doubting the great skill of this illustrious naturalist in vegetable Palæontology, that the specimens from Wilkesbarre and Richmond, being presumed by him to have come from the same geological formation, and the very imperfect condition of the Virginia specimen disguising its peculiarities, he failed in bestowing such attention on the subject as would have assured him that the two were of different species.

According to Brongniart, the *C. arenaceus* occurs associated with *Equisetum columnare*, near Studtgard.

CALAMITES PLANICOSTATUS.

The fossil here referred to is usually met with in the slaty beds containing the *Equisetum columnare*, and is, in some localities, quite as abundant as that plant. The best characterized specimen in my collection has the appearance of a flattened stem, exhibiting several distinct articulations, all entirely devoid of tubercles. Throughout its whole length, this impression is marked by shallow parallel grooves, slightly deepening towards the joints, and distant one from another from the fifteenth to the twentieth of an inch. These grooves are generally prolonged across the joints, so as to be continuous throughout the neighboring divisions of the stem, suffering only a slight flexure and lateral displacement as they cross the articulations, and returning again to the original line. The ribs or ridges between the grooves are smooth and flat, excepting near the joints, where they are slightly but irregularly convex. At many of these joints, are seen small circular scars, like the points of insertion of leaves, arranged at intervals of about half an inch. One or two extremely fine striæ may generally be traced along the middle of each rib.

From the general flatness of the impression, and the great shallowness of the furrows, it might at first be readily taken for a large striated leaf; but, upon removing the coaly film which conceals the articulation, the jointed and stem-like nature of the fossil is indistinctly shown. The great thickness of the coaly layer adjoining this impression upon the surface of the slate, and the number of such impressions found in the layers of a fragment of the rock only one or two inches thick, imply that the hollow stem of the plant which produced them, was extremely thin, and easily compressed. Whether it was of the same genus with the plants whose fossil relics have been arranged under the title of calamites, it would be impossible as yet to determine. As far as may be inferred from external appearances, it would seem to be referable to that group. Ranking it, therefore, for the present, with the long list of *doubtful* fossils included under this generic head, I propose the specific name of *planicostatus*, as descriptive of the remarkable flatness of its ribs.

Tæniopteris magnifolia.

The impressions of this superb plant are found in great numbers in some of the dark gray slaty layers and ferruginous bands above the coal, and even upon the surfaces or partings of certain varieties of the coal itself. This fossil retains so perfectly the delicate markings of the original frond, that I have been able to compare it satisfactorily with the other species of the same genus, figured and described by Brongniart, Phillips, Lindley and Hutton, and Sternberg, and have thence been led to consider it as a new species. The particulars in which it differs from the *Tæniopteris vittata*, Brongn. and *T. scitaminea* (Presl.) Sternberg, the two species which it most nearly resembles, will appear from the following description:

1st. *The form of the frond.* Although among my specimens there is no large frond, in which both the extremities are entire, the numerous fragments of fronds, exhibiting the ends as well as the middle portions of different leaves, enable me very satisfactorily to trace the figure of the frond, in an advanced stage of growth. This may be described as oval-lanceolate, but with this peculiarity, that while the upper or free end is formed by a gradual curving of the margin, from the wide part of the frond toward the end, so as to present a very regular and nearly elliptical sweep, the lower extremity tapers towards the petiole, in a somewhat irregular and undulating manner, and is greatly reduced in width before it terminates. Our fossil thus agrees with the *T. vittata* in the elliptical outline of the upper half of the frond, but differs from it in the undulating margin and more triangular form of the part next the petiole. It is also wider in proportion to its length. It is at once distinguished from the *T. scitaminea*, which in other respects it very closely resembles, by the apex of the latter having a reëntering, cordate curvature.

2d. *The size of the frond.* A comparison of the smaller and more perfect fronds with fragments of the larger ones, often amounting to one half or three fourths of the whole, has enabled me to supply the outline of the deficient portions of many of the latter, and has thus afforded data for measuring a number of the fronds. The following are the dimensions of three, greatly differing in size:

		Inches.
Frond A.	Breadth,	2.4
	Estimated length by several fragments,	14.
Frond B.	Breadth,	4.
	Estimated length,	24.
Frond C.	Breadth,	6.1
	Estimated length,	40.

The breadths here recorded were all carefully measured upon the specimens. The length of A, was deduced from the measured length of a fragment twelve inches long; that of B, from a fragment twenty inches long, and that of C, from several fragments, from six to twelve inches long. The estimated lengths of A and B, are probably a little less than the true lengths.

3. *The Midrib and Petiole.* The Midrib is quite robust, having, in some of the larger impressions, a width of from one third to one half an inch, but gradually tapering towards the upper end, it becomes extremely slender at the apex. On the upper side it is marked by a somewhat deep groove and numerous parallel striæ. The Petiole is thick, rounded at the end, and about one seventh the length of the frond. This slenderness of the midrib towards the upper end, forms another feature of distinction between our fossil and the T. *vittata*, as figured by Brongniart, and in this particular gives it more resemblance to the drawing given by Lindley & Hutton of T. *major*.

4. *The Nervures.* As in the T. *vittata*, T. *scitaminea*, and a few other species, the nervures of our fossil are nearly or exactly at *right angles* to the midrib. They are, however, *far more delicate and numerous than in T. vittata.* Moreover, after a careful examination of the nervures of more than twenty fragments, I have been unable to discover more than three or four instances of their bifurcation, either near the midrib, or at any other part of their length; while, on many large and distinct specimens, not a single example of bifurcation could be found. *Simplicity of the nervures* is, therefore, to be ranked as one of the characters of our fossil. In the T. *vittata*, on the other hand, according to Brongniart, "the nervures are sometimes simple, sometimes bifurcated either towards the base, the middle, or near the extremity;" and in Brongniart's figure, the bifurcated nervures are as numerous as the simple ones, the two being arranged alternately. In Sternberg's definition of the species, a similar frequency of bifurcation is implied by the words "*venis horizontalibus furcatis, cum simplicibus alternantibus.*"

5. *The position and size of the supposed points of fructification.* On many of the fronds of the Virginia fossil an irregular row of circular depressions is seen, on each side of the midrib, and not unfrequently on the midrib itself. These hollows would seem, as in the *vittata*, to mark (according to Brongniart) the position of the roundish groups of capsules. They are, however, much larger than in that species, being from one sixth to one fourth of an inch in diameter, and are placed at unequal intervals asunder, and at rather varying distances from the midrib.

The peculiarities above described, especially the form and size of the frond, and the almost invariable singleness of the nervures, would seem to furnish ample reasons for regarding the Virginia fossil as distinct from either the T. *vittata* or T. *scitaminea*, although nearly allied to both. Looking upon it as forming a new species, I have ventured to give it the title of T. *magnifolia.*

T. magnifolia. Frond, varying from one to six inches in width, and from seven to forty inches in length, curving elliptically towards apex, tapering with an undulating margin towards base, supported by a thick petiole about one seventh the length of the frond, and rounded off at the end. Midrib thick, marked on the superior side by a somewhat deep groove and numerous parallel lines; nervures perpendicular to midrib; simple, or very rarely bifurcated; parallel, distinctly prominent, and numbering, in the large frond, from fifty to sixty to an inch.

The *genus Tæniopteris*, entirely unknown in the carboniferous formation, first makes its appearance in the new red sandstone, and still later, forms, in the lias and öolite, an important and apparently characteristic group. The species most nearly allied to our fossil, namely, T. *vittata*, T. *scitaminea*, T. *major*, and T. *latifolia*, appear to be peculiar to the lower part of the öolite and the lias, either one or all of them being found in this geological position at Hoer, Neuewelt, Whitby, Scarborough, Stonesfield, and other localities.

Speaking of the *vittata*, Brongniart says: "This fern is one of the most common in the Jura formations, and may be regarded as one of the characteristic plants of our third period of vegetation. From a citation of localities, it appears that it has already been found in widely distant places, and that it is especially abundant in the Öolite marls of the coast of Yorkshire."

Pecopteris Whitbiensis. *Brongniart.*

Although fossils of the fern tribe are of very rare occurrence in the strata of which I am now treating, I have been fortunate enough to procure several specimens in a good state of preservation. These I find to be referable to three species, closely resembling, if not identical with species found in the lower part of the Öolite in Europe. The fossil referred to under the present head, corresponds so well with Brongniart's figures and description of P. *Whitbiensis*, that, notwithstanding a slight disagreement in one or two minor points, I cannot but regard it as of the same species.

The leaf is bi-pinnate, the rachis thick and smooth, the pinnæ oblique, opposite, straight, much prolonged, and tapering towards the apex. The pinnules are contiguous, but not confluent; protracted at the upper part of the base, contracted at the lower; they are arcuate-acute, but less so than in Brongniart's figure of

P. *Whitbiensis.* The main nerve, starting from the midrib nearly at right angles, bends gradually upwards, the nervules diverging slowly from this, or springing from the base near the central nerve, are once and twice furcated, and both they and the central nerve are very delicate. In most of these particulars, it will be seen that our fossil agrees precisely with P. *Whitbiensis.* The only points of difference seem to be, a somewhat less acute termination of the pinnules, their rather greater breadth in proportion to their length, and their more delicate nervation. These disagreements are, I presume, too unimportant to separate the Virginia fossil from the P. *Whitbiensis*, especially when so high an authority as Sternberg has united under this title three of Brongniart's species, presenting much greater diversities, namely, P. *Whitbiensis*, P. *Nebbensis*, P. *teneris.*

The importance of this fossil, in determining the age of the strata in which it is found, may be inferred from the statement of Brongniart, that "this plant is altogether peculiar to the Jura formation, and has no analogy with any of those which appertain to the true carboniferous system.

Pecopteris Munsteriana. *Sternberg.*

Of the fossil here referred to, I have met with but one specimen. This consists of a single pinna, with a full array of uncommonly large, and, in general, distinctly marked pinnules. The extraordinary size of the pinnules, and their proximity and mode of attachment to the rachis, might at first lead us to regard this fossil as identical with the *Pecopteris insignis* of the Yorkshire Oölite, described and figured by Lindley and Hutton; but a closer attention to the plan of nervation, and the form and size of the pinnules of the two, discloses very important points of difference. In the P. *insignis*, each nervure, at its junction with the middle nerve, very regularly divides into two branches. In the Virginia fossil, after this forking at the middle nerve, there occurs a further bifurcation of one or of both the branches thus formed. The pinnules of the P. *insignis* are larger than those of our fossil; they are, moreover, of a falcated shape, while those of the Virginia species are nearly or quite straight, and have an ovate termination. Among all the species of Pecopteris described and figured by Sternberg, Brongniart, and Lindley and Hutton, the P. *Munsteriana* is that with which our fossil most nearly corresponds. In the shape of the leaf, and its mode of attachment to the rachis, and in the peculiar plan of nervation, as shown in Sternberg's drawing of P. *Munsteriana*, the agreement is perhaps as close as could be expected, even in two specimens of the same species. The only point of difference between them, appears to be the greater size of the pinnules in the Virginia fossil. As, however, the disparity is not very great, and the smaller pinnules on the Virginia specimens are quite as large as the larger ones in Sternberg's figure, the inequality may probably be explained by difference of age or of position on the leaf.

According to Sternberg, the P. *Munsteriana* occurs at Bullenreit, near Baruth, in strata, referred to the *Lias*.

PECOPTERIS. . . . . .

This specimen consists of several incomplete *pinnæ*, evidently appertaining to a large Pecopteris, of a different species from either of the preceding. The *pinnæ* are straight, regularly tapering towards the extremity, nearly at right angles to the main stem, and closely crowded together. The pinnules arranged alternately on the opposite sides of the midrib, are nearly perpendicular to it, and are attached by the entire base, but quite separated one from another, having no connecting wing. The pinnules, near the base of the *pinnæ*, preserve a nearly uniform breadth, from the attachment to near the extremity, and are then very bluntly rounded off. Those more towards the end of the *pinnæ* are slightly tapering, curve a little upwards, and terminate acutely. A strong ridge marks the position of the middle nerve. Each pinnule is crowded with the impression of *Sori*, forming a row of dots, or of depressions, from six to twelve in number, on each side of the middle nerve; but in no part of the specimen can the nervures be distinctly traced. Of the various species figured, that which seems most nearly to approach our fossil is the *Pecop. obtusifolia* of the Yorkshire Öolite, as represented by Lind. and Hutton, plate CLVIII, figs. 1 and 16. According to the description of these authors, however, the Yorkshire fossil is a much smaller and more delicate plant than ours.

Lycopodites Williamsonis. *Brongn., Prodromus.*

Lycopodites uncifolius. Phillips's Yorkshire.

The fossil impressions referred to this title, comprising different portions of the plant, among which are the head or cone, correspond in almost every particular with the figure of *Lycop. uncifolius*, given by Lindley and Hutton, as copied from Mr. Williamson. "The one, and sometimes two, strongly marked ridges up the centre of each leaf," the "oppositely placed leaves, with the smaller ones between," the scales upon the stems, the cones with "the strongly marked rhomboidal spaces like scars," the peculiar claw-like form of the leaf, especially where full grown, are all distinctly exhibited in the Virginia fossil. Indeed the only points in which it seems at all to differ from the figure of L. *uncifolius* given by Lindley and Hutton, are, that it is smaller in all its dimensions, has apparently a less scaly stem, and has its small leaves less sharply pointed, and less curved than the Yorkshire fossil. Considering these minor differences as affording no sufficient grounds for ranking it as a distinct species, when in other respects the agreement is so striking, I do not hesitate to regard it as either identical with the *Lycopodites uncifolius*, or as a species closely allied to that plant.

Zamites obtusifolius.

The beautiful fossil, which I propose to designate by this title, is found along with the *Lycopodites*, above described, in a state of good preservation, in a dark-gray argillaceous slate, not far above the coal. It has the form of fragments of the leaf, or pinna, one of which, in my collection, though still incomplete, is about eight inches long. The impression of the midrib is nearly straight, gradually tapering towards the outer end of the pinna, and irregularly and rather finely striated. This, when widest, in the larger pinna above mentioned, is about one tenth of an inch across. The leaflets are attached to the midrib by their whole base, and where they unite with it are nearly in contact one with another, but not confluent. They are about one tenth of an inch wide, preserve a nearly uniform breadth from the base outward, and are *bluntly* rounded off at the extremity. They are from one to two inches long, becoming shorter towards the upper end of the leaf, and are either straight or slightly falcated. From the lower end of the leaf to near the upper, the pinnules are placed at an angle of from seventy to eighty degrees with the midrib; at the upper end they make a more acute angle. Each pinnule is marked by from three to six parallel veins, springing from the midrib, and running to the extremity. As yet I have met with no specimen exhibiting the stem and pinnæ in connection, and I am therefore unable to speak of the character of the stem to which these leaves belong.

On comparing this fossil with the figures given by Professor Phillips, and by Lindley and Hutton, of the several species of *Cycadites* or *Pterophyllum*, found in the *Öolite* rocks of Yorkshire, &c., it will be found, along with a marked general resemblance, to present several striking peculiarities. Nor does it bear even as near a specific analogy to the other fossils of the same tribe, figured and described by Sternberg.

The fossil which it most closely resembles is one which I find figured among the illustrations of Captain Grant's interesting 'Memoir on the Geology of Cutch,' (Geol. Trans., vol. 5,) under the title of "*Ptilophyllum acutifolium*." In the latter, however, the leaflets have an "acute apex," and are "imbricated at the base, and attached obliquely," in all of which characters it differs from the Virginia fossil.

In accordance with the generic characters which appear to have guided Prof. Phillips, this fossil would rank as a *Cycadites*, while in obedience to the definition of Brongniart, and Lindley and Hutton, it should be placed in the genus *Pterophyllum*. Preferring what appears to me the simpler arrangement of the *Cycadites* adopted by Sternberg and Presl, I have rather chosen to place it in the comprehensive genus *Zamites* of the latter author, adding the specific name *obtusifolius*, as descriptive of the mode of termination of the leaflets. The propriety of referring it to this genus will at once appear on comparing the above description of the fossil and the accompanying figure, with that part of Sternberg's definition of the genus which relates to the leaves, comprised in the following words:

"*Folia pinnatifida, vel pinnata, pinnis distichis, sessilibus adnatisve, laciniisque integerrimis nervosis, nervi plures, paralleli, in basi pinnarum vel laciniarum juxta depositi.*"

It will be seen that the *Zamites obtusifolius*, as above characterized, bears a close resemblance, in most particulars, to the fossil figured and described by Brongniart, under the title of *Filicites vittarioides*, and since described by Sternberg as *Zamites blechnoides.* Vide Hist. des Veg. Fos: Liv. 11, p. 391, and Sternberg's Versuch, &c., part 7 and 8, p. 200. Though this fossil is spoken of by Brongniart as having been sent to him by Prof. Silliman, from the coal-field of Eastern Virginia, I have been unable to find it anywhere in this region. The points in which, according to the description of Brongniart it differs from *Z. obtusifolius*, are the confluent form of the pinnules where they join the midrib, and the invariable presence of but *two nerves* in each pinnule.

Zamites tenuistriatus.

The impressions of this fossil, which I have thus far met with, are imperfect and rather obscure, consisting of disjoined leaflets and incomplete fronds. They are, however, sufficiently distinct to show the peculiar form of the leaflets, their mode of attachment to the midrib, and their nervation.

The leaflets, varying from three fourths of an inch to one inch in length, and from one eighth to one tenth of an inch in breadth, where widest, are sharply elliptical at base, attached directly to the midrib, and taper with great regularity from the place of greatest width (about one fourth the whole length from the midrib) to their termination. The nervures are parallel, numerous, and so delicate as to be but obscurely traceable on most of the impressions.

The fossil to which this appears to bear most analogy, is the *Zamites Whitbiensis* of Sternberg; but the leaflets of the Virginia plant are much smaller, more delicate, and of a narrower form, and the nervures much more minute.

Zamites.

One of the most abundant of all the fossil relics found in the dark-colored slates a short distance above the coal, and sometimes interlaminated with the upper part of the seam, consists of long flat impressions, covered with straight parallel ribs or veins from thirty to forty to the inch. These impressions lie closely upon each other, between the parallel laminæ of the slate, and appear to be of extreme thinness. The great distance to which the parallel ribs may be traced, without any indications of an articulation, and the close proximity of the impressions, would seem to exclude the supposition of their being compressed stems of a *Calamite*, while their narrowness and nearly uniform width, and some obscure appearances of attachment to a midrib, incline me to refer them to some very large *Cycadeous* plant.

The above-described fossils comprise the more important, though not all of the vegetable remains which I have yet been able to procure in a state of sufficient preservation to be of much interest for purposes of comparison. Further explorations in which I am now engaged, will, it is hoped, add many new ones to the list, and enable me clearly to determine the characters of a number of interesting, but as yet obscure plants, of which I now have specimens.

Of animal remains, the only specimens, thus far met with, are a single species of *fish*, and the *teeth* of what was probably a *Saurian*. The former, which has been accurately described by Mr. Redfield, is referred by him to his new genus *Catopterus*, under the title of *Catopterus macrurus*.* Its remains are met with profusely, though seldom in good preservation, in the black bituminous slates and lead-colored argillaceous sandstones, im-

* See American Journal of Science, for 1841, vol. 41. p. 27.

mediately upon, and for some distance above, the coal. In some localities the rhombic scales occur in immense numbers, blended with vegetable impressions, not only in these beds, but in the upper part of the coal itself. The teeth I have found both in the finer grits, and associated with the fish scales immediately upon, and in, the coal.

Description of the Tin Veins of Jackson, N. H. By Charles T. Jackson, M. D., *State Geologist*.

A few minute and scattered crystals of oxide of tin had been noticed in the albite rock of Chesterfield,* and in a block of granite at Goshen,† anterior to the discovery of the tin veins of New Hampshire, which are to be described in the present memoir. We have been informed by Prof. W. B. Rogers, at this meeting, that a few scattered crystals of this ore were observed in the auriferous veins of Virginia. No regular veins of the tin ore have been found at any of the above-mentioned localities. I have the satisfaction of announcing to the Association, that in 1840 I discovered several regular veins of the oxide of tin in the town of Jackson, N. H., on the estate of Mr. William Eastman. I have laid before you specimens of the ore, and an ingot of the metal extracted from it. Also, specimens of the accompanying or associated minerals which occur in the tin veins.

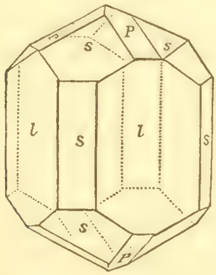
The locality where these ores are found, is situated on a hill a little to the eastward of the White Mountains. The rocks which compose the mass of the hill are mica slate, gneiss, and granite, with occasional dykes of compact and porphyritic greenstone trap. The stratified rocks run in a northwest by west and southeast by south direction, and dip to the northeast by east thirty degrees.

* See Haidinger's Translation of Mohs' Mineralogy, Vol. II, p. 387, Edinburgh, 1825.

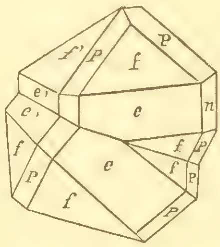
† See Prof. Hitchcock's Report on the Geology of Massachusetts, page 74.

Across the strata at acute angles, veins of granite intersect the mica slate, and run north and south. The granite veins and the mica slate and gneiss rocks are intersected by trap dykes running northeast and southwest.

Included in the granite veins, and passing into the mica slate, occurs a vein of arsenical iron, or arsenical pyrites, which runs north forty degrees east, south forty degrees west, and is from one to four inches in width, and at least three hundred and twenty-eight feet in length. This vein is cut off by the trap dyke, and it was at the junction of this dyke with the vein that I first noticed the occurrence of crystals of the oxide of tin, associated with copper pyrites, the ore being abundantly mixed throughout the vein stone, which is a deep chocolate-brown mica slate, deeply colored by tungstate of manganese and iron. The oxide of tin in that part of the vein is highly crystalline; and distinct crystals, generally as large as a grain of wheat, are thickly implanted in it, and may be picked or washed out for examination. The largest which were obtained are one quarter of an inch in length, and their forms either that of the right square prism, modified by numerous facets, or modifications of the primary octahedron, with a square base, as represented in Mohs' Mineralogy, Vol. II, plate XIX, fig. 102. See p. 81. Hemitropic crystals also abound, having the form as represented in fig. 2.



1.



2.

The color of the crystallized oxide of tin is of a deep hair brown; rarely, it is almost black. The small crystals are translucent, and are, when viewed by transmitted light, of a yellowish brown color. Their lustre, when free from striæ, is adamantine. They are sufficiently hard to scratch phosphate of lime, but not quite so hard as adularia. Specific gravity of the compact ore, containing a few particles of quartz, 6.458 to 6.487. The compact ore is found investing the walls of the veins, and the smallest ones have a thin layer of quartz running through the centre, in which are implanted numerous brilliant crystals of the oxide of tin, which are remarkably perfect. Before the blowpipe alone, this ore is infusible; nor does it dissolve in glass of borax, or in biphosphate of soda. It is insoluble in acids. Pulverized and mixed with powdered charcoal, with two thirds carbonate of soda and one third glass of borax, it is readily reduced on charcoal to metallic tin, which may be thus separated in brilliant globules, or in a small button.

These globules, when acted upon by nitric acid, are converted into insoluble stannic acid, which is of a white color, and is also insoluble in acids. It was evident, when a fragment of the tin ore was reduced to the metallic state, that the metal was nearly equal to three fourths of the bulk of the ore reduced.

On pulverizing and washing a quantity of the vein stone containing crystals and grains of the oxide of tin, a heavy ore was obtained, containing a few particles of the arsenical pyrites and a little copper ore, which, on being roasted, to free it from arsenic, and reduced, yielded, according to the purity of the specimen, from thirty to fifty per cent. of tin. A selected specimen of the compact oxide, reduced to the metallic state, yielded seventy-three per cent. of tin, which was perfectly pure.

An average lot of the fragments of ore taken from the small veins, when reduced, yielded sixty-four per cent. of metal, which was impure, but on being refined gave fifty-four per cent. of pure tin.

Five ounces of the pulverized ore was taken for reduction. It was first boiled with a little nitric acid, to remove the soluble oxides and impurities, and then reduced in a crucible lined with lampblack, at a forge heat, and yielded three ounces of pure tin, which was cast into an ingot. This is the specimen now laid before the Association. A piece of the ingot was cut off and rolled out into a sheet, which was also exhibited. This specimen is, in fact, the first ingot of tin that has been extracted from an ore found in this country.

Since the discovery of the largest tin vein in Jackson, three others of smaller dimensions have been found, which yield a perfectly compact and nearly pure oxide of tin. One of them widens as it descends in the rock.

Minerals found associated with the Tin Ore of Jackson, N. H.

Oxide of tin in crystals and in compact veins of tin-stone, arsenical iron, and arseniate of iron, are abundant. Copper pyrites or bi-sulphuret of copper and iron, in disseminated masses. Native copper, in thin folia, rare; oxide of iron, not abundant, but mixed with the mica slate of the vein; iron pyrites, in crystals, abundant, disseminated. Wolfram disseminated in the veinstone not crystallized; fluor spar, investing the walls of the veins, color light pink, or white and transparent; mica, brown-colored, in fine scales; black tourmaline, radiated in small crystals in the granite; phosphate of lime rare, yellowish-colored crystals; quartz in crystals and crystalline grains; it occurs also in thin layers, forming the middle seams in the small veins, serving as a separation of the investing coats of compact tin ore on the sides of the veins, the deposit of tin ore having been made on the walls of the fissure.

It will be perceived, that the above-mentioned minerals are those which generally occur in the principal tin mines of Cornwall, Bohemia, and Saxony; and hence we may infer, that the circumstances under which the ores in these different regions were deposited, were similar, if not identical. It gives us reason to believe, that the New Hampshire tin mines may prove valuable. The largest part of the vein was eight inches wide, and it contracted to the southward to a vein one inch in width. The small veins run east and west, or across the strata, and they are from one fourth of an inch to one inch wide; but are much richer than those of larger dimensions. The ore is generally pure compact oxide of tin. It is probable, that, in working the mine, numerous dilatations of the metalliferous lode will occur, forming stockwerkes and pockets of tin-stone. As yet, no excavations have been made to a greater depth than three feet; and hence we are unable to estimate the probable value of the ore which may be obtained by mining. Tracing the principal vein to the southward, we lost sight of it in the valley; but on the rising ground beyond we again found the ore, with its usual associated minerals. This locality is one fourth of a mile south of the principal vein, and in the direction of its course.

On revisiting this locality, I discovered several new veins of compact oxide of tin, and obtained ninety-eight pounds of the ore, which yields on the average forty per cent. of tin, while the clean ore freed from the rock yields seventy-three per cent. of metal. By a single assay of this ore I obtained from twenty-one ounces of rock and ore, taken just as it was blasted out, eleven and a half ounces of pure tin.

Remarks on the Theory of the formation of Tin Veins.

M. Daubrée, Ingéneur des Mines, has published some interesting remarks on the theory of tin veins. (Annales des Mines, tome XX, 4me livraison July and August, 1841.)

He considers the origin of the oxide of tin in veins to have arisen from the volatilization by heat of the fluoride of tin from the interior of the globe; and that, as the fluoride, thus sublimed into crevices of the rocks, was decomposed by water or earthy bases, the oxide of tin was deposited on the surfaces of the fissures, and the veins became filled with the ore.

In order to prove the presence of fluorine, he cites the fact of the constant occurrence of fluor spar in tin mines, and also regards the investing layers and crystals of quartz as formed by the sublimation of fluorides. He also supposes, that the combinations of boron and fluorine were raised in vapor, and that the occurrence of tourmaline in all tin veins is a proof that boron was present at the time of their formation, that mineral containing boracic acid. Mica also, containing fluoric acid, is a frequent associated mineral in tin veins.

It is interesting to observe the remarkable agreement of the facts noticed at Jackson with those cited by M. Daubrée. It is evident, at our locality, that the oxide of tin was deposited in layers on the sides of the fissured rocks, and that the veins were thus filled up with the oxide by deposition from the sides to the middle.

This author refers to the sublimation of chloride of iron in the crater of Vesuvius as presenting analogous phenomena. There, as originally observed by M. Gay Lussac, the specular oxide of iron which invests the fissures in the lava, and lines the walls of the caverns, is produced by the sublimation of chloride of iron, which is decomposed by the agency of steam, chlor-hydric acid being formed, and peroxide of iron deposited.

Remarks on Zinc, Lead, and Copper Ores of New Hampshire. By C. T. Jackson.

It is surprising that the rich veins of blende or sulphuret of zinc, which occur so abundantly in this country should be wholly neglected, when it is so easy to extract the metal from the ore. By roasting the sulphuret of zinc at a dull red heat in a reverberatory furnace, it is readily converted into the oxide of zinc, which, being mixed with charcoal and distilled, will yield forty per cent. of the metal. A remarkably pure yellow blende occurs in the town of Eaton, N. H.; and several hundred tons of that ore have been raised during the working of the mine for lead, and it still remains around the mouth of the mine neglected.

Black blende also occurs in large veins in the town of Warren, N. H., and smaller ones are found at the lead mines of Shelburne, and in Lyman.

Assays of Blende.

Two thousand grains of the Eaton blende having been roasted, and thus converted into oxide of zinc, yielded on distillation seven hundred and seventy-seven grains of pure zinc, or 38.8 per cent. About two per cent. of the zinc was lost by adhesion to the neck of the retort, and we may reckon the yield of the ore in the large way at forty per cent.

Two thousand grains of the black blende of Warren yielded by the same operations four hundred grains of pure distilled zinc, or twenty per cent. In the large way it would give from twenty-five to thirty per cent. of the metal.

I exhibited to the Association specimens of the ores here mentioned, with the metals extracted from them.

Assay of the Galena of Shelburne, N. H.

Two thousand grains of the galena yielded fifteen hundred and fifty-eight grains of lead, or 77.8 per cent. The lead cupelled gave 2.5 grains of pure silver, or two and a half pounds to the ton of ore.

The galena of Eaton also contains sufficient proportion of silver to repay the expense of extracting it from the lead. It contains eighty-four per cent. of lead, and a ton of the lead will yield two pounds of silver.

Provided the zinc and lead ores are both wrought, it might prove profitable to renew operations at these mines.

At Warren, copper pyrites of great purity occurs, associated with tremolite rock, the ore yielding, when pure, thirty-two per cent. of copper, by assay. If the copper ores are wrought, it will be easy to manufacture brass from this copper, and the oxide of zinc prepared from the blende occurring near the copper vein. Researches are now going on to ascertain whether the copper vein becomes richer and more solid as it descends into the rock.

On the Connection of Thermal Springs in Virginia, with Anticlinal Axes and Faults. By William B. Rogers, *Professor of Natural Philosophy in the University of Virginia.*

The proximity of some of the noted Thermal Springs of Europe to lines of remarkable disturbance in the stratification, appears to have been early noticed. Whitehurst long ago, in his Theory of the Earth, alluded to this peculiarity of geological position, when speaking of the waters of Matlock. In recent times similar observations have been greatly multiplied. Stifft has made particular mention of saddle-shaped elevations of the strata, often accompanied by fractures, as marking the position of the thermals of Nassau. Hoffman has described the waters of Pyrmont, as flowing out in a valley of elevation of a nearly circular form. Conybeare and Buckland have called attention to the remarkable dislocation in the neighborhood of the Bristol hot wells, and Lyell and Murchison have noticed similar phenomena in the vicinity of Aix, in Provence; while Forbes has made known the important fact, that a large class of thermals in the Pyrenees, and probably elsewhere, flow out at the common boundary of the hypogene and stratified rocks.

Further instances of the association of thermal springs with dislocations of the strata, and other marks of uplifting and intrusive action, are mentioned by Dr. Gardner in his valuable treatise on mineral and thermal springs, and still more lately by Dr. Daubeny, in his lucid and comprehensive report on the same subject to the British Association. To the latter distinguished geologist we are indebted for many interesting speculations founded on these and other peculiarities of thermal springs, viewed in their connection with the theory of volcanic agency, of which he has long been the ingenious and zealous advocate; and to Professor Bischoff, of Bonn, we are under equal obligations for an elaborate and masterly analysis of the mechanical, geological, and chemical conditions connected with the flow of such waters, together with an explanation of their temperature and impregnation, deduced from the theory of a general subterranean heat.

With the exception of brief and rather incidental notices published by myself and others, and the communications of Dr. Daubeny to Silliman's Journal and the Ashmolean Society, no account has yet been given of the peculiarities of geological structure, associated with the thermal springs of the United States. Indeed, the supposed rareness of their occurrence in this country, compared with many parts of Europe, and their comparatively slight excess of temperature in most instances over the ordinary springs, have naturally rendered them less inviting as subjects of observation. It is hoped, however, that the details about to be presented, by proving their frequency in a part of the Appalachian chain, in which until of late years only a few were believed to exist, will encourage a search for them in other parts of this extended mountain belt.

My objects in the present communication are *first*, to call attention to the very *frequent* occurrence of thermal springs among the axes of the Appalachian chain in Virginia; *secondly*, to indicate certain *laws of position*, by which I have found them to be governed, and *thirdly*, to point out the important bearings of those facts when connected with the peculiar geology of the region, upon the theory of a generally diffused internal heat.

According to the views of Professors Daubeny and Bischoff, every spring is to be regarded as *Thermal*, whose temperature exceeds the atmospheric mean of the region in which it is situated: and in conformity with this definition, the former of these philosophers has proposed, "in constructing a scale of temperature in regard to them, to calculate it not by their actual warmth, but by the degree of their excess above the mean of the climate." The propriety of this suggestion, which he has himself carried into execution in the very valuable Table appended to his 'Report on Mineral and Thermal Waters,' is obvious upon a moment's consideration. Thus we know, that the ordinary superficial springs under the equator have a temperature as high as some of the celebrated thermal waters of Europe and America. In Mexico the temperature of seventy-two degrees, corresponding with the mean of the climate, belongs to the common springs, while in Virginia the same temperature renders decidedly thermal the well-known fountains of the Sweet Spring Valley, which rise in a region whose average is about fifty-one degrees.

Admitting that the elevated temperature, observed in mines and Artesian wells, is dependent upon a generally diffused internal heat, increasing with the depth, and not upon chemical or volcanic agencies of local operation, the class of thermal waters, as above described, ought to include a large proportion of such springs as are not of superficial origin. Indeed, under any view of the sources of their temperature, all springs ought to be included in this class whose heat is invariable, or when liable to change never sinks below the atmospheric mean of the place.* Some decidedly thermal springs, as, for example, the White Sulphur Springs of Virginia, display considerable variations of temperature with the change of seasons or of weather. It would, therefore, not be correct to assume *permanency* of heat as the criterion of thermal character, however completely, in the ordinary circumstances of springs, such permanency would seem to prove that the waters in which it is observed belong to the thermal class. It may be fairly assumed in general, that a spring presenting a uniform temperature, or one which, in its fluctuations, never descends below the atmospheric mean, cannot be dependent for its heat upon the atmosphere and superficial strata. Hence the general dissemination of such springs over a widely extended region, *furnishes the strongest evidence for the existence of a perennial source of heat within the earth.*

As remarked by Bischoff, the coldest springs of uniform temperature, provided they do not derive their waters from a neighboring mountain, will exhibit the nearest approximation to the average temperature of the country; but will always be a little, though it may be a very little higher. Guided by these views, he has shown, from extensive observations in Germany and other parts of Europe, that thermal springs are of far more frequent occurrence than had been supposed, and, indeed, that nearly all the copious mineral springs there, and probably, by inference, in

* Of course, this is intended to include springs originating in glaciers or near the tops of high mountains.

other parts of the Continent, are of this denomination. Out of *twenty* mineral springs in the vicinity of the Lacher See, which he continued to observe at different seasons for several years, the coldest always exceeded the mean of the place by about two degrees and twenty-five minutes, thus proving them all to be unquestionably thermal. Similar observations on the springs of the Dippe, Jordan, Pader, and Heder, flowing from the foot of the chalk rocks of the Teutoburges-wald, brought to light the fact, that out of *sixty-six* running fresh-water springs, only three had a temperature below forty-seven degrees seventy-five minutes, the mean of the place, making *sixty-three* to belong to the thermal class. In like manner Prof. Forbes found the temperature of a number of copious springs upon the Rhine, not before supposed to be thermal, to exceed by several degrees the mean of the place.

Observations of these *slightly thermal*, as well as of warmer springs, though thus numerous in some parts of Europe, have perhaps been too much confined to such regions as are known or may be supposed to have been at one time the theatre of *local volcanic activity*, to admit of our inferring, with confidence, that the elevation of temperature thus observed, is the result of a generally pervasive heat within the earth. Indeed, the very frequent occurrence of intrusive igneous masses, among the rocks of a large part of Europe, is calculated to weaken the force of such an inference generally, as applied to that portion of the earth's crust.

In this country, the vast belt of mountains occupied by the Appalachian strata, presents, as I conceive, a region peculiarly favorable for *unambiguous* observations of this class, in consequence of the absence, excepting along its eastern border, of trappean or other erupted rocks. It is therefore greatly to be regretted, that so little has been done towards an accurate determination of the temperature of the perennial springs of this region, more particularly of such as are situated near conspicuous axes and lines of fault. From my own observations made from time to time during the last eight years, chiefly in Virginia, I am led to conclude that a great proportion of the copious and constant springs of this belt, and more especially those of our great limestone valley, are truly though slightly thermal, and that they owe to a deep subterranean source the remarkable uniformity of temperature they exhibit. As, however, accurate determinations of the atmospheric mean, as well as minute observations on the springs at various seasons, are requisite in deciding with certainty upon their thermal character, and as we are yet very imperfectly provided with these data, the question, with regard to a great number of our bold springs, must still remain unsettled. I therefore restrict myself in the present paper to a notice of such as are decidedly and unequivocally thermal.

The following Tables comprise all the well-marked thermal springs of Virginia, either previously known, or which have been brought to light by myself and my assistants, in the survey of the State.

Table I, relating principally to the thermals which are best known and most resorted to by invalids, includes, in regard to most of them, a statement of the names and relative quantities of the evolved gases, with the names of the gaseous and principal solid ingredients.

In Table II, these particulars are omitted, as being of less present interest with regard to most of the springs it embraces, but occasional notices are annexed of the evolved gases and of the contents of the waters. I may add, that a minute account of the ingredients of our thermal and mineral springs generally, derived from a long series of analyses in which I have been engaged for many years, will be made public in another form. It will be seen, that some of the springs, embraced in Table II, have a temperature but little above the atmospheric mean, yet their thermal character is believed to have been fully established by the permanency of this excess.

CATALOGUE OF THE THERMAL

Table I.

	Name of Spring.	Geographical Position.	Geological Position.
	Warm Springs,	W'm Spring Valley, Bath County,	In anticlinal axis of Formation II, of Va. and Pa. Reports,
1	1. Principal Bath,		
2	2. Drinking Spring,		
	Hot Springs,	Same Valley as above, in Bath County,	In same axis as above,
3	1. Gentleman's Boiler,		
4	2. Spout Bath,		
5	3. Red Spring,		
6	4. Pleasure Bath,		
7	5. Barrel Spring,		
8	6. Sweet Spring,		
9	7. Gent's Lower Spout,		
10	8. Ladies' Hot Spout,		
11	*Gap Spring,*	N. W. of W'm Spring on road to Bull Pasture,	In the above axis near N.W. termina. of expos. For. II.
	Sweet Alum Springs,	3 miles S. W. Hot Springs,	In the above axis, For. II.
12	1. Toothache Spring,		
13	2. Healing Spring,		
14	3. Spring near Road,		
15	*Falling Spring,*	Near Covington,	Near S. W. end of same axis, For. II.
	Sweet Springs,	Sweet Spring Valley, Allegheny County,	Anticlinal axis passing into fault. N. W. side of II.
16	1. Drinking Spr. near Hotel,		
17	2. Old Red Spring,		
18	3. Rogers' Red Spring, or Champaigne Spring,		
19	4. Bubbling Fountain,		
20	5. Western Spring,		
	Snake Run Springs,	Near N. E. end Sw. Spring Valley,	In same axis, termination of For. II.
21	1. Two large Springs,		
22	2. Less, but Cold Springs,		
	Bath Springs,	Warm Spring Ridge, Bath, Morgan County,	S. E. flank of anticl. axis of Capon Mt. in For. VII.
23	1. Spring near Hotel,		
24	2. Southwest of (1)		
25	3 Southwest of (2)		
26	*White Sulphur,*	Greenbrier County,	In anticl. axis of For. VII.
27	*Wilson's Thermal,*	Near Long's Entry Creek, Botetourt County,	In anticl. of For. VII. N.W. of axis of Biggs's Mt.
28	*McHenry's Spring,*	Near N. Fork of Holston River, Scott County,	Near fault bringing For. II. in con. with For. XI, in XI.

SPRINGS OF VIRGINIA.

TABLE I — CONTINUED.

	Temp. of spring.	Temp. of place.	Gases evolved.				Gaseous Ingredients.				Princi. solid ingredients.
			Nit.	Ox.	C. ac.	S. Hyd.	100 cubic inches contain				Total 100 in cubic inches.
							Nit.	Ox.	C. ac.	S. Hyd.	
1	97½°	51°	98.	2.6	¾	¼	1.62	trace	2.64	0.21	1 { 10.64 grs. consist. of Sul. Lime, S. Mag. S. Soda. Carb. Lime.
2	96	"	"	"	"	"	"	"	"	"	2. C. Magnesia, &c.
3	106	"	84.8	5.	10.2	"	1.79	0.32	11.	trace	3 { 13.25 grs. do. with a decided amount of carbonate of iron.
4	108	"	....	....	......	......	1.77	0.28	11.8	......	
5	105	"	84.	0	11.	"	1.50	0.24	11.6	......	
6	102	"	87.5	0	12.5	......	....	....	......	......	4. 12.73 grs. same.
7	102½	"	75.	6.	19	......	1.80	0.2	11.5	......	5. 15.61 grs. same.
8	93	"	....	....	......	......	2.10	0.35	11.7	......	7. 13.12 grs. same.
9	103	......	....	....	......	......	....	....	......	......	8. 14.5 grs. same.
10	......	......	....	....	......	......	....	....	......	......	9. 42.75 grs. same.
11	71	"	....	....	......	......	....	....	......	......	10. 13.8 grs. same.
											Chlorides of Sodium, Calcium & Mag. exist in all these waters in small amount; also very faint traces of Iodine. The same is true of those which follow as far as 26.
12	85										
13	83										
14	74										
15	62	"									
16	74	......	71.7	....	28.3	......	1.87	trace	31.87	trace	16 { 32.67 grs. main ingredient same as above.
17	75	......	77.3	....	22.7	......	2.12	"	35.6	......	17 { 33.81 grs. same, with more Carb. Iron.
18	{ 76 / 78	......	62.5	....	37.5	......	2.57	0.20	46.1	......	18 { 40.76 grs. same, with more Carb. Iron.
19	74	......	82.	5.	13						
20	72	......	77.2	....	22.8	......	1.6	trace	30.55	......	20. 41.21 grs. same.
											23, 21, 25 { 4.75 grs. chiefly Carb. Lime, and Mag. and Sulph. of same basis.
21	72										
22	67										26. 65.54 grs. Carb. Lime and Mag., Sulph. Lime, Mag. & Soda, chloride of Sodium, Magn. and Calcium, Sul. Hyd. of Magnesium, &c. Sulph. Iron, a marked amount of Iodine, Sulphur blended with organic matter.
23	73	52?	89.7	9.2	1.1	......	1.32	0.12	1.14	......	
24	74	"	"	"	"	......	"	"	"	......	
25	72.5	"	"	"	"	......	"	"	"	......	
26	61 to 65	......	....	....	......	......	1.78	0.19	2.07	......	
27	65	"	....	....	......	......	....	....	......	......	27 { 22.85 grs. same as 1, 2, &c.
28	68	53?	....	....	......	......	....	....	......	......	28. 26.04 grs. same.

Table II.

	Temp. of Spring.	Temp. of place.	Name of Spring.	Geographical Position.	Geological Position.
			Bon Springs.	Cedar creek valley,	In steep anticlinal axis
29	57.	52?	1. Enclosed Spring,	Shenandoah co.	of For. VI. Springs bold
30	56.		2. Open Spring,		and constant; some gas
31	55.75		3. Open Spring,		— Nit. and C. acid. . . . .
			Capon, or Cacapon,	Near Watson town,	N. W. side of anticl.
32	64.	. . . . . .	1. Principal Spring,	Hampshire co.	axis of Paddy Mt. from
33	57.		2. Sp. higher up Mt.		vert. strata of For. VII.
34	55.		3. Sp. " than (2)		Copious and constant.
35	54.		4. Sp. " than (3)		S. E. side of anticl. of
			Keyser's Thermal,	Near Clifton forge, on	Red Patch Mt. From
36	64.	. . . . . .	1. Large Spring.	Jackson river, Rock-	For. VI. Copious and
37	61.		2. Five smaller Sp. .	bridge co.	constant. Some gas — Nit. Carb. acid and Ox.
38	62.	. . . . . .	*Mill Mt. Spring,*	Panther gap, Mill Mt., Rockbridge co.	S. E. side of anticl. of Mill Mt. From For. VI. Copious and constant.
39	56.	. . . . . .	*Haycock's Spring,* . . .	N. W. side of Big Sandy ridge, Hardy county.	Anticlinal axis of North river Mt. from For. VI. Very bold and constant.
40	60. 61.6	. .	*Pearce's Springs,*	Near Pearce's furnace, N. W. side of Paddy's Mt.	N. W. side of anticl. of Paddy's cove. Junction of For. VI. and VII.
41	55.	. . . . . .	*Spr'gs near Wardensville,*	Hardy county.	N. W. side of anticl. of Chestnut Ridge, from For. VII.
42	56.	. . . . . .	*Busby's Spring.*	W. of Wardensville, Hardy co.	N. W. side of anticl. of Big Sandy. From junc. of For VII. and VIII.
43	61.5	51. 52?	*Nap's Creek Spring,* .	Near Huntersville, Pocahontas county.	Anticl. axis of Brown's Mt. For. VI. Much gas. Nit. C. acid.
			Walker's valley Sp.	Valley of Walker's	Axis in For. II. Rocks
44	57.5	. . . . . .	1. Largest Spring, .	Creek, Wythe co.	nearly vertical. Bold. Gas
			2. Less Springs, . .	. . . .	No gas.
45	56.		*Sp. near Galbraith's,*	. . . .	Steep beds of For. II.
			1. Lower Spring, . .	South of Draper's val-	Near fault of Draper's
46	56.	. . . . . .	2. Upper Spring, . . .	ley, Wythe co.	valley. Very bold sp'gs.
47	56.				Gas.
48	60.	. . . . . .	Spr. A great group of Thermals, covering nearly half an acre, . .	On Hunting Camp Creek, near junc. with Wolf cr., Giles' co.	Near N. E. end of great Anticl. of Burk's Gard. From For. VII.
49	60.	. . . . . .	*Kimberling Spring,* . .	Kimberling fork, Giles' co.	Anticl. of Little Flat top Mt. For VI.
50	56.	. . . . . .	*Edmonson's Big Sp.* .	Near Roanoke river. Floyd co.	Fault; in F. II. Copious. Much gas. Nit. &c.
51	57.	. . . . . .	*Limestone Spring,* . . .	Near E. base of Little North Mt., Shenandoah county.	Inversion of For. II. on III. with fault. Flows from II. Bold. No gas.
52	66.	. . . . . .	*Limestone Spring,* . . .	Near Milford, Page county.	Inverted axis of For. II. Very copious.
53	70.	. . . . . .	*Strecklar's Spring,* . .	Entrance of Streck's Gap, Rockbridge co.	Inversion of For. II. on III. with fault. Flows from II. Bold. Nit. Ox. and C. acid.
		. . . . . .	*Buford's gap Springs.*	S. E. of Blue ridge.	Junction of For. I. with
54	66.		1st Spring,	at Buford's Gap, Bed-	Hypogene rocks.
55	72.		2d Spring,	ford co.	
56	75.		3d Spring,		

The details embraced in the preceding tables of our thermal springs, will, I think, justify the assertion, that in no region hitherto described is the connection of springs of this class with the structural features of the district in which they occur, so uniformly and extensively displayed as in our Appalachian belt. The *fifty-six* springs here enumerated embrace *twenty-five* distinct lines and individual localities, situated in various and remote parts of the valley, and the mountainous belt adjoining it on the northwest, making in all an area of about fifteen thousand square miles. *Forty-six* of these springs are situated on or adjacent to anticlinal axes, *seven* on or near lines of fault and inversion, and *three*, the only group of this kind yet known in Virginia, close to the point of junction of the Appalachian with the Hypogene rocks.

It may therefore be announced as the prevailing *law*, as regards the more decided thermals of Virginia, and I have reason to believe of other parts of the Appalachian belt, that *they issue from the lines of anticlinal axes, or from points very near such lines.*

A glance at the several short sections accompanying this paper, aided by the following brief comments, will serve more particularly to illustrate the conditions under which they thus generally occur, and to impart just conceptions of the structure of the districts in which they are situated.* (Plate XVI.)

SECTION I. *From the Warm Springs to the Little North Mountain.*

SECTION II. *Passing through the Hot Springs.*

SECTION III. *Passing through the Gap Spring and Ebbing Spring.*

SECTION IV. *Through axis at Keyser's Springs.*

In the first of these Sections are embraced three thermal localities, presenting distinct geological conditions. In the most western, that of the well-known Warm Springs, the water comes to the surface in the line of an anticlinal axis. In the next, that at the Mill Mountain, it flows out on the southeastern side of the

* The scale of the Sections is two and a half miles to the inch, or twice that of the large State map. The eastern part of Section VIII is, by mistake, too much expanded.

axis, and in the third it issues from rocks, presenting a great inversion, accompanied by a fault.

The *Warm Springs* rise to the surface through fissures, in a massive bluish limestone, a part of Formation II, of the Virginia and Pennsylvania Reports, and corresponding to the Black river limestone of the New York geologists. This rock forms the surface of a long and narrow anticlinal valley, extending from beyond the Gap Spring (Section III) to the neighborhood of the Falling Spring, (Table I, No. 15,) a distance of about thirty miles, nearly in a direction from northeast to southwest. Beyond this, towards the northeast, the higher formations close over the limestone, forming a lofty unbroken mountain, in the prolongation of which the axis gradually dies out. A similar though more rapid change terminates the axis at the southwest, its entire length being about sixty miles.

The rocks on the northwest side of this axis, forming the Little Warm Spring mountain, are in general either vertical, or overturned, while those on the southeast, constituting the lofty and massive range of the Warm Spring mountain proper, present a moderate southeastern dip, excepting at a few points where the inclination for a short distance is much steeper.* The line of thermals situated in this axis, includes those of Table I, from 1 to 15, inclusive. Of these, the least thermal, the Gap Spring and Falling Spring, are found towards the extremities of the anticlinal valley; those nearer the centre of its length, the Warm Springs and Sweet Alum Springs, have a much higher temperature, and the Hot Springs, occupying a central position, are the warmest of all. At the latter point, the flexure of the strata appears to have attained its maximum, and is of the *folded* kind, the rocks of the northwest side of the valley, and of the Little Warm Spring mountain, being inverted for a thickness of about three thousand feet.

The amount of water issuing from these springs is so great as to form the chief part of the Warm Spring creek, Cedar creek, and other streams flowing out of the valley towards the north-

* This unusually steep inclination on the southeast side of the axis, is seen opposite the Warm Springs on the main road.

west. At all these points much gaseous matter is evolved along with the water, consisting in great part of nitrogen, with some carbonic acid, a very little and in certain cases no oxygen, and at two or three points a slight admixture of sulphureted hydrogen.

The position of this valley between two lofty ridges, which uniting at its opposite extremes form a complete enclosure around it, and the steep inclination of the strata along the western part of its surface, are just such conditions as might be expected to give rise to a large accumulation of water at great depth, and to furnish a hydrostatic force capable of raising it to the surface. It appears to me, therefore, that in speculating upon the mechanical agencies concerned in the emissions of these thermals, we are not called upon to imagine any other force than that of the simple pressure of aqueous columns, either continuous or interrupted by gases accumulated in the same fissures or cavities within the earth. Nor, in tracing to their origin the temperature, evolved gases, and the chemical ingredients of these waters, do I conceive that any further conditions are required, than the access of the air and meteoric waters to rocky masses at a great depth below the surface, and whose temperature, due to that depth, sustains the chemical actions necessary to give the proper impregnation to the springs.

In glancing the eye along Section I, it will be seen that the flexures of the strata are such as to give the axis-planes an *oblique* position, dipping towards the southeast; a structure equally distinct also in the other sections, and which is in conformity with a *general law*, already announced by my brother, Prof. H. D. Rogers and myself, in a joint paper 'On the Structure of the Appalachian Chain,' read to the Association.* In consequence of such a flexure, the strata of the Mill Mountain, on the western side, are thrown into an inverted position; those on the east, in which the *Thermal of Panther Gap* rises, preserving a moderate dip towards the southeast. This bold spring, accompanied by a good deal of gas, chiefly nitrogen, issues from beds of limestone belonging to

* To this paper, and the accompanying Sections and Diagrams, I would refer for a full exposition of this law, and for explanations of the terms *normal and folded flexures*, *axis-plane*, &c., used in the present article.

our For. VI, nearly equivalent to the Pentamerus limestone of New York.

The same conditions accompany the group of thermals marked on Section IV. The strata here are more slightly inverted on the northwest, and their *curvature* is so well preserved, even in the massive beds of sandstone, (For. IV, Shawangunk grit of New York,) as to present, in the grand exposure at Clifton forge, a vast rocky arch of more than half a mile in span.

The thermal at the southeastern extremity of Section I, is associated with a different structure. The limestone (For. II) of the great valley is here, as in most places near the foot of the Little North Mountain, *thrown over upon For. III.* This inversion, due to a folded axis lying parallel to and southeast of that ridge, though it often extends entirely through the mountain, at this point ceases with the eastern outcrop of the lower beds of For. IV. At the junction of Formations II and III, the latter is much crushed, and a slight fault occurs. It is near this spot, in the limestone, that the warm waters make their escape. The thermal, marked at the southeastern extremity of Section X, occurs under precisely the same conditions, rising in the same rocks, thrown into the same inverted attitude.

Section V. *Across the Sweet Spring Valley.*

The structure of this valley, like that of the Warm Springs, is due to a great anticlinal axis. Commencing at a point southwestward of the termination of the latter, this valley extends for about fifteen miles in a nearly west-southwest direction, bounded by the Sweet Spring or Peters's Mountain on the southeast, and by the Snake Run or Little Mountain on the opposite side. Where the limestone, For. II, begins to be exposed by the opening of a great anticlinal range of For. III and IV, and for a short distance towards the southwest, the strata have a *normal flexure*, those on the northwest side of the axis dipping steeply towards the northwest. But as we proceed towards the southwest, the flexure increasing, causes an inversion of the strata on the northwest side, accompanied by an occasional crushing and partial concealment of the slate rocks of For. III. These conditions, first seen at the group of thermals on Snake Run, (Table I, Nos. 21, 22,) continue, with some fluctuations, to near the southwest end of the valley, the amount of dislocation gradually but irregularly augmenting as we trace the Little Mountain in that direction. Beyond this point the fault rapidly increases, so that in the distance of a few miles not only the rocks of the Little Mountain, but all the strata intervening between For. II, and For. XI, (carboniferous limestone) have been swallowed up. In this condition, occasionally varied by the intrusion of in-wedged knobs or masses of the ingulfed strata, we may trace this extraordinary dislocation along the northwest base of the Peters's and East River mountains for more than fifty miles, after which it is still further continued with a new topography.

The *Sweet Springs* flow out from the steep-dipping and inverted limestone near the centre of the valley; the *Red Springs* and *Snake Run group* from points nearer the junction of this rock with For. III, of the Little Mountain. The streams fed by these copious fountains, flowing towards the northwest by narrow transverse valleys through the Little and Snake Run mountains, have accumulated a great thickness of tufaceous deposit, forming in the neighborhood of the Red Springs a succession of picturesque cascades.

Gas, consisting of nitrogen with a considerable amount of carbonic acid, escapes freely from all these springs, rising from the Sweet Springs in copious streams. Much dissolved carbonic acid is also present, rendering most of these waters decidedly acidulous, and enabling them to retain in solution a marked proportion of carbonate of iron, as well as the more usual ingredients, carbonates of lime and magnesia.*

SECTION VI. *Through the White Sulphur Springs.*

The axis in which the White Sulphur Springs arise, and that of the thermal of Brown's Mountain, (Table II, No. 43,) are nearly though not exactly in the same line. They are further

* These are the only decidedly acidulous springs in Virginia, and I believe the only ones in the United States, excepting a few which, like Saratoga, contain also a large amount of chloride of sodium.

from the southeastern margin of the Appalachian belt than any others referred to in the tables, their distance from the Blue ridge, in a direct transverse line, being about forty miles. The White Sulphur axis, exposing For. VII, at the springs, dies out in a short distance towards the southwest; but, traced in the opposite direction, expands into a considerable ridge, bringing into view the upper part of For. VII, here of inconsiderable thickness, and eventually terminates in a roll of the slates of For. VIII, near Anthony's Creek. In the neighborhood of the springs the flexure of the strata is remarkably abrupt, the gentle slope on the southeastern, passing into a vertical or slightly inverted dip on the opposite side of the axis. With the exception of this and another adjacent but very inconsiderable line of exposures, the surface for many miles on either side is occupied by the slates and sandstones of Fors. VIII and IX, bent and contorted by numerous lesser axes, and in the Allegheny Mountain and the numerous adjoining hills, carved by denudation into a variety of picturesque forms.

The waters of the White Sulphur are copious, but accompanied by very little evolved gas. The few bubbles I have succeeded in entrapping, proved to be nearly all nitrogen, but it is uncertain whether they arose with the water from the depths below, or were developed in the basin of the spring.

Though decidedly thermal, these waters have a fluctuating temperature, never, however, as I think, approaching nearer than ten degrees to the atmospheric mean.* They form the only instance within my knowledge of a strongly sulphureous and at the same time thermal water in the United States; and in these respects bear a close analogy to certain thermals of the Pyrenees.†

* Dr. Daubeny, who visited these springs when in this country, did not advert to their being thermal. See Silliman's Journal, April, 1839.

† The *plumose, filamentous* growth, involving a large amount of hydrated sulphur, which lines the basin and outlet of these waters, and which from its color has given rise to the name of White Sulphur, is also found in other sulphureous springs in the State, and has caused the adoption of this name as descriptive of such springs as a *class*, notwithstanding their want of agreement in other and far more important particulars. Organic products of another kind, developed in the enclosures of the Red, Blue, Gray, Crimson, and Green Sulphur Springs, and whose true nature was also first suggested by myself, (see Hare's Chemistry, 1838,) have by a like connection originated the names by which these springs

SECTION VII. *Through Wilson's Thermal and across Garden Mountain.*

This section includes a partial view of the great anticlinal of the Garden Mountain, exhibiting a striking example of the folded form of flexure, with an extensive inversion on the northwest side. Behind this, towards the northwest, lies the anticlinal of Biggs's Mountain, separated from the former by an irregular trough of folded slates (For. VIII); and at the western base of Biggs's Mountain occurs the lesser axis, in which the thermal here referred to rises to the surface. While the axis of Biggs's Mountain brings up the whole thickness of For. III, *doubled upon itself*, that of Biggs's Mountain exposes no strata lower than For. V, (Medina sandstone and Clinton group of New York,) over which the beds of VI and VII are seen bending, in a rather steep normal flexure, to be again elevated in part in the low ridge of VII, (Oriskany sandstone of New York,) from which the thermal issues. The point of exit of the waters is in nearly vertical strata, a little west of the axes-plane. Beyond this, towards the northwest, is a wide expanse of For. VIII, greatly folded and contorted, in which, at no great distance from

are respectively known. Observations beyond, as well as in the State, have satisfied me, that similar organic products are to be met with, in some one or more forms, in *all the sulphureous waters* of the Appalachian belt, and that they are *peculiar* to waters of this class. Having read with great interest Dr. Lankester's "notice of the plants and animals found in the sulphureous waters in Yorkshire," as given in the Report of the British Association for 1840, I have been much gratified at finding these opinions corroborated by the observations of that gentleman in regard to the sulphureous waters of Harrowgate, Askerna, and the neighboring district, and I have enjoyed no little surprise in recognizing in the conferva which at those places "collects in large quantities around the sides of the wells," and in the animal deposit, "varying from a light pink to a rose color," the objects which impart such beauty to some of our celebrated sulphureous springs, and which six years ago I pronounced to be of "vegeto-animal" origin. I may here add, by an experiment made at that time on the water of the White Sulphur, which in its basin and outlet produces little or none of the rose-colored deposit, I found that I could at will give rise to it by collecting the liquid in an adjoining cavity in the dark sulphureous mud—and I remarked that *before* the material of the rosy film collected on the surface beneath, it continued diffused in the liquid for some time like a faint pink cloud, changing its position and its density. This, with other observations, suggested the idea of its being due to animalculæ, which under certain favorable conditions as to light, and perhaps temperature, quiescence, and the contact of particular substances, would always display themselves in our sulphureous waters. For the distinct determination of the forms and relations of these organic objects by the microscope, we owe our thanks to Dr. Lankester.

the thermal, occurs Dibbrell's Spring, a cold alkalino-sulphureous water, such as *characterizes* the lower and more calcareous portion of these slaty rocks.

The discharge of water at Wilson's thermal is abundant, but is accompanied by very little gas. The spring contains a small amount of uncombined carbonic acid, together with a considerable proportion of saline matter.

SECTION VIII. *From Bath across the Cacapon Mountain.*

The Cacapon or Capon Mountain, formed by the union of several contiguous parallel axes, which arise at various points within a distance of fifty miles from the Potomac river, attains its greatest altitude and breadth about eighteen miles southwestward of the line of our Section, beyond which, in its prolongation towards the river, it gradually declines. Where most largely developed, a slight roll of the strata makes its appearance near its southeastern base, which, soon assuming more importance, forms the distinct anticlinal of Warm Spring Ridge. This, in its prolongation towards the northwest, gradually loses its anticlinal character by the obliteration of the narrow trough between it and the Cacapon axis, and forms at the Potomac a low flanking hill of southeast dipping rocks. Where the thermals of Bath arise, the anticlinal flexure is still in part preserved in a sharp but transient change of dip in the rocks a little westward of the Springs. Owing to an error in reducing this Section, the space between the centre of the Eastern Cacapon axis and the position of the springs, is much too great. Contracting this interval, it will appear that the position of these thermals agrees in all important points with that of the springs on the southeastern flank of the Mill Mountain, Section I, and of the group in Section IV.

These copious springs make their appearance near the junction of Fors. VII and VIII, at the southeastern base of the Warm Spring Ridge, here faced by the massive jointed sandstone of the former. The gas which accompanies the water, though consisting mainly of nitrogen, contains a rather larger proportion of oxygen than is found in the other principal thermals of the State. The amount of solid matters present in these waters is extremely small.

SECTION IX. *From the Cacapon Springs to the Little North Mountain.*

SECTION X. *From the Great North to the Little North Mountain, through Bon Springs.*

In the former of these Sections, we have a view of the folded or inverted form of flexure, both in the anticlinal of the Paddy and Great North Mountain, and in the trough between the former and the Little North Mountain. In the narrow anticlinal valley hemmed in by the wild and rugged heights of the Paddy and Great North Mountains, no decidedly thermal springs have yet been discovered, though the structure and topography of the place would seem highly favorable to their production. Perhaps their absence may be explained by the peculiarly shattered condition of the strata occupying the surface of the valley, and forming the enclosing mountains, especially that on the northwest, in virtue of which ready channels may be furnished conveying them to other and remote points of discharge. This opinion is, I conceive, supported by the conditions under which the Cacapon Springs occur. These thermals, as indicated on the Section, make their appearance on the northwest side of the Great North Mountain. They are four in number, and situated at different levels, the lowest, which is also the warmest, flowing from For. VII, near its junction with VIII, and the others successively lower in temperature and higher in position, issuing from VI and V. They are all copious and constant, and yield but little gas. In the lower or principal spring, the chief ingredients are carbonates and sulphates of lime and magnesia, and sulphate of soda.

SECTION X, parallel to the preceding, and a few miles northeastward of it, includes, it will be seen, three separate localities of thermal springs, the first or Pearce's Spring, (Table II, No. 40,) at the western base of the Great North Mountain, the second or Bon Springs, (Nos. 29, 30, 31,) in the Cedar Creek Valley, and the third, an unnamed spring, (No. 51,) rising near the eastern base of the Little North Mountain, all comprised in a distance which, in a direct line, is less than six miles.

On comparing the two Sections it will be seen, that the anticlinal valley of the Paddy and Great North mountains contracts towards the northeast, the inversion on its northwestern side being at the same time replaced by steep northwestern dips. This change goes on augmenting, until, at no great distance northeast of the present section, the valley terminates in a great anticlinal mountain of normal flexure, formed by the now united rocks of the Paddy and Great North mountains. While this change is in progress, two small axes, commencing a little northeastwards of Section IX, make their appearance in the Cedar Creek Valley, lifting For. VII and then VI, from beneath the slate, and forming the low range called the Sugar Hills. It is in the more important of these axes, that the *Bon Springs* are situated. This is a sharp anticlinal, giving exit to the water through For. VI. The spring to the east of this flows from the limestone near the southeastern base of the Little North Mountain, issuing as before noticed from a line of inversion and fault. *Pearce's thermal* agrees in position, as regards the axis, with the Cacapon Springs, rising near the junction of steep-dipping VI and VII.

All these springs evolve more or less gas, chiefly nitrogen, and the Bon Springs contain a considerable amount of calcareous and magnesian salts.

Deeming the preceding details sufficient to illustrate the conditions under which the various classes of thermals in Virginia present themselves, it would be unnecessary, as well as tiresome, to enumerate similar particulars in regard to the numerous other warm springs referred to in the preceding tables. I may here, however, remark, that but few of our thermals, not flowing in axes, rise, as in the case of the Mill Mountain and Keyser's Springs, on the *southeastern side* of the axis-plane. Indeed, out of the whole number included in the tables, I know of but three groups so situated, and these are exhibited on the Sections. *All the others issue from the steep-dipping on inverted strata on the northwest side of the anticlinals*, and this may be laid down as the general *law of their position.*

Of the *mechanical and chemical agencies* concerned in the production of some of these thermal springs, I have already briefly expressed my views, while describing the structure of the Warm Spring Valley, and its enclosing mountains; and I need hardly add, that the same general explanation is equally applicable to the other thermals, situated in anticlinal valleys. In carrying out this view more in detail, and especially in applying it to cases like that of the Sweet Spring Valley, where the anticlinal axis passes into a prolonged line of fault, it has appeared to me to be necessary as well as reasonable to admit, *first*, that the subterranean channels, which operate both in furnishing the requisite supplies of water and air to the depths below, and in forwarding the thermal stream under hydrostatic pressure, must have a direction conforming in general to the strike of the rocks; and, *secondly*, that the direction of the downward flow of the meteoric waters, is in a great degree determined by the natural partings of the strata, or, in other words, by the plane of dip.

These conditions granted, it will at once appear, that in a *closed* anticlinal valley, like that of the warm and hot springs, thermals, if occurring at all, might be expected to appear along its whole length, in a linear arrangement, and near its western boundary. It would also seem, in this case, that the height of the comparatively elevated ground at the two ends of the valley would determine the hydrostatic column employed in bringing the water to the surface.

Where, however, the valley is *closed only at one end*, as in that of the Sweet Springs, the case is, I think, different. Thermals may of course be looked for towards the closed end, and in this position they are found; but it is a remarkable fact, that the line of fault constituting the prolongation of the axis of the Sweet Springs, though continued to a distance of more than fifty miles, *does not disclose a single thermal* throughout its whole extent, nor have I yet succeeded in discovering more than one spring of the kind, in other parts of the Appalachian chain, where similar geological conditions prevail. On the other hand, in the prolonged line of fault running along the southeastern base of the Little North Mountain, close to the northwestern margin of our great Limestone Valley, and at other points, where the same structure exists, many thermals have been detected, several of which, from their marked elevation of temperature, are included in the preceding catalogue.

These results are, I think, sufficiently explained by reverting to the two conditions above specified, in connection with the form of the surface, and the position of the strata in the vicinity of these faults. In the *first* case, where For. II. rests upon the overturned beds of For. XI, the strata composing the narrow belt of the former, along the northwest base of the great range of Peters's and East River Mountain, and southeast of the line of fault, as well as the rocks of these ridges, dip at a moderate angle towards the southeast, and therefore *away from the fault.* On the opposite, or northwestern side of the fault, the country is comparatively *level*, the Little Mountain, which formed the western boundary of the Sweet Spring Valley having been ingulfed in the vast hiatus. Hence, though the rocks of XI, for a short distance northwest of the dislocation, (through the breadth over which this formation continues inverted,) actually dip towards the fault, the flat topography on the northwest is not such as naturally affords a hydrostatic column sufficient to raise the water from a great depth to the surface, along the line of fracture. Nor could we expect the heights of Peters's Mountain on the southeast to furnish such a column, since the *southeast dip* of the strata there would rather *oppose* than facilitate the passage of the liquid towards the fault, and would most probably convey it to subterranean tracts lying still further towards the southeast. There is also another feature, to which, as I conceive, some influence is to be ascribed in preventing the occurrence of thermals along this line. The strata of For. XI, although overturned where they are in contact with For. II, continue in this position across but a *narrow belt* towards the northwest, and by a rapid curvature below are soon brought into a very gentle northwest dip, or into a horizontal attitude. Their upturned edges could receive directly from the atmosphere but small supplies, and these, most probably, in part at least, would be conveyed away towards the gradually declining level on the northwest.

Turning now to the *second case*, of which we have an example in the fault adjacent to the southeastern base of the Little North Mountain, we at once discern this important difference, that while the direction of the dip and inversion is the same as in the preceding, the *high grounds* of the Little North Mountain lie to the *northwest*. Hence the downward drainage between the strata on the flank of this ridge, conforming to the southeastern dip of the rocks, must be *towards the fault*, and the hydrostatic columns communicating with the heights, and following the plane of dip, will in many cases have sufficient power to force up the heated waters to the surface, at certain points along or near this line.

The numerous class of thermals whose point of issue is *exterior* to the bounding ridges of an anticlinal valley, owe their origin, as I conceive, to the same general agencies as have been above considered. Bearing in mind, that in the great majority of cases they flow out from the *northwestern* boundary, the vertical or inverted rocks of which are greatly shattered, and that their point of exit is generally *below* the level of the valley, it is reasonable to suppose that, in many instances, they have been conveyed away from beneath the surface of the valley, when, in a less fissured condition of the strata towards the northwest, they would have been forced to rise at some point within its confines. In many cases, too, the downward drainage of the northwestern ridge itself is fully adequate to carry the requisite amount of fluid to the seat of heating and chemical action, and, by hydrostatic power, to raise it again to the surface at a much lower level.

In speculating with regard to those thermals which issue at or near the base of a continuous anticlinal mountain, it is important to bear in mind, that while cracks and partings are found generally attendant upon flexures of the strata, these openings are by far the most numerous and extensive in that part of the curve where the change of direction is most abrupt. Hence they will be found descending in the interior of the mountain, much in the direction of the *axis-plane*, and will lie nearer to the northwestern than the southeastern side. The meteoric waters supplied through these channels, will find an exit either by the natural slope of the gently dipping rocks on the southeast of the anticlinal, or through the fissures of the shattered and steeply inclined or inverted strata on the northwest. Where but little of this fissuring occurs on the northwest side, they would meet with least obstruction by flowing in the opposite course, and might, therefore, be looked for on the southeast. Such would seem to be the case with the thermals of the Mill Mountain and Keyser's, (Sections I, and IV,) where the steeply inclined strata are comparatively entire. But, as formerly remarked, the usual position of thermals is on the other side of the anticlinal axes.

It may here be added, that where such springs present a temperature but little above the atmospheric mean, it is unnecessary, in accounting for their heat, to suppose that the water has been conveyed to any very considerable depth below the base of the mountain, as the subterranean line of equal temperature (chthonisothermal line), deflected *upwards* by a massive and steep anticlinal range, would come nearer to the general surface.

Such is a sketch of the views to which I have been led in considering the positions occupied by our thermals, in connection with the probable mechanical agencies by which their waters are accumulated and brought to the surface. Though in some degree hypothetical, as must be all attempts at explaining the unseen mechanism of nature, they are, I think, in harmony with observation, and at all events possess the merit of agreeing in general principles with doctrines sanctioned by the authority of such names as Arago and Bischoff.

As regards the *evolved gases* and the *chemical ingredients* of these springs, my opinions, like those of others who have speculated on this subject, are, confessedly, far from satisfactory. While I am inclined, in some respects, to agree with the views which have been so ably advocated by Dr. Daubeny, in relation to the origin of the gases and other matters associated with thermal waters, I am by no means prepared to adopt the hypothesis, that such impregnations are chiefly due to the *chemical action of the metallic bases of the alkalies and earths;* much less can I accede to the opinion, that the *heat* of our thermals, as well as that of the rocks from which it is directly derived, is due to what is usually termed *volcanic action.*

Deferring my objections to these views to a later head, I would venture to throw out a suggestion as regards the evolution of *nitrogen* from these and other thermals, which appears to me not unworthy of consideration. Admitting, with Dr. Daubeny, what I think extremely probable, that this gas, as it appears in thermals, is but a *residuum* of the atmospheric air which, conveyed from the surface to the source of heat below, has there been partially or entirely deprived of its oxygen, I would inquire, whether the composition of the rocky beds through which the atmosphere is thus conducted is not itself capable of explaining the result.

The limestone For. II, and the slates forming a part of For. I, always contain more or less protoxide of iron and carbonaceous matter, even after long exposure to the action of the weather. Where freshly taken from a new excavation at some depth, the latter rocks abound in the protoxide, and the limestone exhibits nearly all its iron in that stage of oxidation. It would therefore seem probable, that these and the other strata deposited beneath the Appalachian sea, contain, at great depths, this oxide to the exclusion of the sesquioxide. Looking to the large accumulation of the latter in a hydrated state, segregated in various parts of these several formations, it is not unreasonable to infer an even greater proportion of the protoxide in the deeply buried strata than would correspond to the whole quantity of iron combined in the rock above. That the presence of diffused organic matter, such as we know to have been deposited with the other materials of the strata, would secure the protoxide from further oxidation, while still in contact with the waters of our great Appalachian ocean, is a result in harmony with what we witness in our present seas, and with the known chemical relations of the substances concerned. Conceding, then, the existence of the protoxide in due proportion in these older formations, and imagining the air to obtain access to these strata at a depth at which the temperature is sufficiently high to cause a rapid absorption of the oxygen by the protoxide, we should have a large amount of the residuary nitrogen evolved. The carbonaceous matter* also would help to rob the air of oxygen, and aid in the production of the carbonic acid, by which the nitrogen is uniformly accompanied, although it is to the calcination of calcareous rocks that, in common with others, I would refer most of the carbonic acid which our thermal waters contain.

The conjectures thus thrown out, though, as I think, not entirely useless, are offered with that distrust which must always attach to speculations that cannot be brought to the touchstone of actual observation, and more especially, too, from the fact, that they do not appear to have suggested themselves with any force to the able philosophers who have investigated this subject. That I may not be misconceived, I here beg to remark, that I have no disposition to *deny* the hypothesis of the metallic bases, as applied to volcanoes, or even to some thermal springs. On the other hand, I would adopt it as a *part* of the general theory of the causes concerned in the formation of the early crust of the globe from a molten, and chiefly metallic mass. But, in this *later stage* in the history of our earth, I would venture to doubt the propriety of resorting to it in explaining the phenomena of thermal waters in general, and more particularly of those to which my own observations have been directed; and I would give a hearty welcome to any theory which, dispensing with the necessity of penetrating to such enormous depths in search of the unoxidated metals, would explain the chemical characters of these waters by *the known properties of the rocks*, in connection with *a generally diffused internal heat.*

In considering the bearing of the preceding details respecting the thermals of Virginia upon the doctrine of a general subterranean heat, as compared with that of local foci of volcanic action, there is one fact in the geology of our Appalachian region, par-

* Quickly volatilized and combined with oxygen, its power to arrest the oxidation of the protoxide, or to reduce the peroxide when formed, would not, I conceive, be called into play. But even if it were, the difficulty would not be so great as where potassium and sodium are regarded as among the chief oxidizing agents. For in this latter case, what becomes of any carbonic acid which, evolved at the focus of activity, is brought in contact with these metals?

ticularly deserving of attention. I mean, *the almost entire absence, over its vast surface, of igneous or volcanic rocks.* These occur at only four or five points, without any observable relation to axes, and away from the neighborhood of any known thermals, and are in such small amount as together not to cover an area of more than ten acres. Add to the preceding this further fact, that our thermals are not confined to particular lines or axes, but *are scattered at remote points over the whole region*, and it will at once appear, with how much more reason they may be referred to a pervasive subterranean heat, than to points or lines of volcanic action. To apply the latter explanation, we must give to these local foci a *diffusion* beneath the surface, which would, in fact, amount to abandoning the doctrine of merely local heating action, and admitting that of a general internal heat; while, in adopting this latter, we see, in the peculiar positions of our thermals in reference to axes, *simply those mechanical conditions which favor the access of air and water to the deep-seated, and therefore hot strata in the interior, and their expulsion at the surface.*

Adopting the language used by the eminently philosophic Phillips, when referring to arguments urged in favor of the hypothesis of local volcanic action, as the cause of thermal springs in general, I would say, "These arguments, when taken in connection, appear to us to prove, that the heat of the springs is derived from the *depths of the channels* in which they flow below the surface," and "it seems unnecessary to appeal to local volcanic excitement for an effect which spreads, both in time and area, far beyond the traces of purely volcanic phenomena." Such being the inferences of one of the ablest of geologists, from a comparison of the chemical and geological relations of the thermals of the old world, with what *augmented* force may they not be reiterated, after the preceding developement of these relations in a region which, like our Appalachian chain, is almost destitute of even a trace of proper volcanic action!

Notes on the Geology of several parts of Western Asia: founded chiefly on Specimens and Descriptions from American Missionaries. By Edward Hitchcock, LL. D., *Professor of Chemistry and Natural History in Amherst College, Massachusetts.*

For several years past, I have from time to time received specimens of rocks and minerals from American missionaries located in Western Asia, often accompanied by full descriptions. My collection from that part of the world (including about one hundred specimens from India, Ceylon, and China, sent by Rev. E. Burgess, N. Ward, and E. C. Bridgman, also missionaries) amounts to six hundred and sixty-two specimens: and, since the geology of those countries is so little known, it has seemed to me that these specimens and descriptions would enable me to present to this Association some Notes concerning it, that might be of value. We cannot, indeed, expect to obtain, from specimens thus sent, a regular history of the geological structure of those wide regions; but even glimpses may be important, and assist future explorers. Specimens have been received from the following gentlemen; most of whom I have known in the interesting relation of pupils:

Rev. Justin Perkins, located at Ooroomiah, in Persia.
" Story Hebard, at Beyroot, in Syria.
" Benjamin Schneider, at Broosa, in Asia Minor.
" Oliver Philander Powers, at Broosa, in Asia Minor.
" Henry Homes, at Constantinople.
" James L. Merrick, at Tabreez, in Persia.
" Henry J. Van Lennep, at Smyrna.
" J. J. Robertson, D. D., at Athens and Constantinople.
" Cyrus Hamlin, at Constantinople.
Mr. Alexander G. Paspati, at Constantinople.
" Homan Hallock, at Malta and Smyrna.

I ought to mention, also, the valuable information which I have obtained from the recent very able and learned work, entitled 'Biblical Researches in Arabia, Palestine, and Syria, by' Professor Edward Robinson of this country, and Rev. Eli Smith, American Missionary at Beyroot.' I have been allowed, also, to have access to several rare specimens deposited in the Collection of the American Board of Commissioners for Foreign Missions in Boston.

Most of the gentlemen whom I have named, would disclaim all pretensions to practical skill in geology. But of one of them, from whom I received the largest number of specimens, I may speak with more freedom, since he is no longer among the living. I refer to the Rev. STORY HEBARD. Were this the proper place and occasion, it would afford me great pleasure to bear public testimony to his amiable and gentlemanly character and high moral worth, as a tribute to the memory of a beloved pupil and friend. It is, however, proper to say, that, having devoted himself to the profession of a teacher, he gave special attention to chemistry, mineralogy, and geology. With this view, he became my assistant in the laboratory, and in the geological survey of Massachusetts. When he went out to Syria, therefore, I could not doubt that he would give special attention to the geological structure of that country, so far as he could, consistently with the higher duties of his benevolent mission. And the box of specimens which I received from him, gave ample evidence of the extent of his researches, especially on Lebanon and Anti-Lebanon. I have reason to suppose that he was engaged in a systematic examination of that region, with the intention of giving the result ultimately to the world. But whether he left any notes on the subject, I am not informed. I am not without fears, however, that the imperfect notices which I shall give in this paper, may prove almost the only public memento of this department of his labors. He was just commencing a course of lectures on geology and natural history to the Arabic youth, in the seminary of which he was the head. But an inscrutable Providence has terminated, in a manner that seems to us premature, his worldly plans and labors, and the expectations of his friends; leaving to them only the melancholy duty of gathering up the fragments of his scientific efforts, and dedicating them to the dead.

In giving an account of the specimens and facts in my possession, relating chiefly to Western Asia, it will promote brevity, to arrange the countries from whence they came into groups.

The first group will embrace Egypt, Arabia, Palestine, Syria, and the island of Malta.

The second group will comprehend several districts in the western part of Asia Minor, and a few islands in the Grecian Archipelago.

The third group will include Armenia and Persia.

My specimens from Syria, amounting to more than one hundred, were furnished by Mr. Hebard: those from Palestine, by Messrs. Hebard and Homes: those from Egypt, and the Grecian islands, chiefly by Dr. Robertson: and those from Malta, by Mr. Hallock. The numbers by which the specimens will be indicated generally in this paper, are those which they bear in my cabinet, which is deposited in Amherst College.

Before proceeding to details, I ought to remark, that I have not had an opportunity of perusing, except in condensed notices, several recent papers and volumes concerning the countries from which my specimens came, and which doubtless contain many statements respecting their geology: such as the papers of Botta, Strickland, and Hamilton, upon Syria and Asia Minor; and the travels of Schubert, Hamilton, and Ainsworth. In some cases, therefore, my remarks may have been anticipated. But it would be strange, if some new facts should not be derived from a source so entirely independent of the one just mentioned as that from which my information comes, in countries whose geology is so little known. And, besides, the two sets of observations may serve to correct or confirm each other.

I begin with a few remarks upon the peninsula of Sinai and Arabia Petræa; chiefly because we find there a granite nucleus, as striking as any on the globe. It has long been known that the lofty and naked group of mountains that have received the general name of Sinai, are mainly composed of granite, or rather of syenitic granite. The highest peak, called St. Catharine, is eight thousand and sixty-three Paris feet above the ocean. A specimen from this mountain, in the collection at the rooms of the American Board of Foreign Missions in Boston, is a gray syenite, the specks of hornblende being considerably numerous, but small. It contains no mica. Another specimen from the peak that goes by the name of Horeb, is reddish, and contains very little hornblende. This summit is very probably the Sinai of Scripture, where the moral law was given: and though these mountains have been visited by so many sagacious travellers, for many hundred of years, and inhabited by learned monks, yet it is a curious fact, that this spot should be first identified in the nineteenth century, by two American travellers: and that Messrs. Robinson and Smith have identified it, will, I think, be manifest to any one who will carefully examine their researches.

I noticed at the Missionary Rooms, a crystal of quartz from Mount St. Catharine, three quarters of an inch in diameter, incrusted with minute crystals of epidote: also fibrous red hematite from Fursh el Khijan, two hours east of Wady Bijah in Mount Sinai. In the same collection is a specimen of rock salt, from the "Head of Wady el Tayibah, where the Israelites turned to encamp by the Red Sea." Dr. Anderson allowed me to take the fragment No. 424 for chemical examination. I suspected from its aspect that it might be a recent deposit; but careful examination enabled me to find in it several fragments of chalky limestone; and hence I suspect it to occur in that rock; which, as we shall see, is connected with the rock salt near the Dead Sea. A solution of the specimen from Sinai, gave a distinct precipitate to chloride of barium, to oxalate of ammonia, and ammoniaco-phosphate of soda; showing the presence of a sulphate, also lime and magnesia: but in less quantity than is usual in fossil rock salt. I could detect in it neither iodine nor bromine. I have no information as to the extent of the deposit.

The syenite of Sinai is traversed by many dykes of trap rock, probably greenstone; and in approaching it from Egypt, Robinson and Smith describe a formation of porphyry. In passing from Sinai to Akabah, they described the hills of granite as frequently capped in a singular manner with sandstone. In the great desert between Sinai and Palestine, the hills appear to be mainly composed of limestone, chiefly the chalky variety, and probably belonging to the cretaceous formation. Sixty or seventy miles northeast of Akabah, which stands at the head of the eastern branch of the Red Sea, is the remarkable gorge where once stood the capital of Edom, now called Petra. And from the descriptions given us by those who have visited it, we must consider it highly probable, that the rock forming the gorge is the new red sandstone; though no organic relics have been described in it. This formation probably also extends southerly far towards Sinai, and northerly an unknown distance.

It would not be strange if the syenite of Mount Sinai should be found to extend continuously beneath the Red Sea, to the famous quarries of red granite at Syene, in Upper Egypt. In regard to the latter rock (No. 107) it may perhaps appear presumptuous in me to suggest the suspicion, that some of it ought to be regarded as gneiss. This thought first occurred to me, on examining a similar rock in southeastern Massachusetts; which I at first supposed to be granite, but afterwards became satisfied was granitic gneiss. This suggestion, however, is not of much importance: for often there is not a more difficult point in geology, than to draw the line between granite and gneiss. Yet I find that the more I examine, the more disposed I am to reduce the limits of granite, and enlarge those of gneiss.

We have all heard much of the deserts of Arabia, and of the moving sand-hills there. No. 553 is a specimen of these sands: and, on examination with the glass, I was surprised to find them to consist of fragments of genuine yellow quartz, not to be distinguished by the eye from topaz. The grains are very much rounded. Was this done by water, or by wind, or by both? This specimen was presented by the Rev. Justin Perkins of Persia; to whom it was given by a Mahommedan pilgrim, on his way from Mecca, or Medina, to Persia. He stated, that the caravan was a fortnight in crossing these sands.

My specimens from Egypt are too few, perhaps, to throw any light upon the geology of that country. The silicified wood, No. 396, is the most interesting. This is from the extensive deposit near Cairo. "For miles," says Dr. Robertson, "the surface is covered with fragments, from the size of this specimen to many feet in length." The texture of the siliceous matter is much coarser than that of the well-known specimens from Antigua: so coarse, indeed, that Professor Bailey could not detect the minuter vessels of the wood by a microscopical examination. The concentric layers, however, are very distinct to the naked eye, as well as the medullary rays, with no appearance of parenchymatous tissue. We may hence safely refer this specimen to an exogenous dicotyledon; and with nearly equal confidence to the tribe of coniferæ; and very probably it may belong to tertiary strata. The fossil crab, No. 386, from near Cairo, and the nummulites, No. 387, from the pyramids of Gizeh, are interesting chiefly from their localities. Dr. Robertson refers the former to tertiary limestone; and I notice that his specimens are usually named with great accuracy. No. 394 is a quartzose conglomerate from the mountain Djebel Aschar, near Cairo. No. 385 is beautiful, calcareous, translucent alabaster, which is employed by the Pasha of Egypt in building a palace at Cairo. This rock has evidently been deposited from springs, like the famous alabaster near Tabreez in Persia, to be hereafter described; but I have not been informed of the Egyptian locality. This alabaster is entirely soluble in nitric acid, except a mere trace of earthy matter. And I was surprised not to be able to detect in it any iron or magnesia; substances considerably abundant, as we shall see, in the Persian alabaster. It may, therefore, be considered a pure carbonate of lime; and I regret not to know its locality.

Whoever receives specimens of rocks from the countries bordering on the Mediterranean, will be struck with the predominance of limestone over all others. And he will notice a striking identity of characters in those from different countries. My specimens exhibit three distinct varieties. The first are chalky and pulverulent, of a white or yellowish color, and in fact pass into true chalk; the second are compact and yellowish; and the third are highly crystalline. The last class is always associated, as in this country, with gneiss or the older slaty rocks. The first class belongs either to the tertiary or cretaceous groups,—more commonly to the latter; and the second class, I strongly suspect, will be found to correspond to the Öolitic group of continental

Europe. The first and second classes will first demand our attention.

We now know enough of the rocks around the Mediterranean to be certain, that these compact and chalky limestones extend through a considerable part of Egypt, thence into the northern part of Arabia, thence through Palestine and Syria to Mount Lebanon and Anti-Lebanon, which are mainly composed of these rocks. Similar rocks occur, also, in the island of Malta; and the compact variety, at least, in Greece and Asia Minor. Out of the large number of specimens in my collection, I have examined a few analytically; chiefly, however, with a view to determine whether any of them are dolomitic.

In No. 15, which is the common rock of Mount Lebanon, according to Mr. Hebard, I found in one hundred parts, by a not very satisfactory analysis, although repeated,

Earthy residuum,	1.0
Carbonate of lime,	61.3
Carbonate of magnesia,	37.7
	100.0

No. 25 lies below the conglomerate and chalky limestone, one mile west of Damascus; and I found in one hundred parts,

Earthy residuum,	0.33
Carbonate of magnesia,	4.13
Carbonate of lime,	95.54
	100.00

No. 5 is the rock on which Jerusalem is built; and it was used in building the Temple of Solomon, some of whose foundation-stones still remain, as seems to be made very probable by the researches of Robinson and Smith in that city. One hundred parts of this stone gave

Earthy residuum,	1.00
Carbonate of magnesia,	0.83
Carbonate of lime,	98.17
	100.00

No. 54, from the supposed site of the garden of Gethsemane, appears to be an agatized mass of silica, containing a little carbonate of lime. In one hundred parts I found

Earthy residuum,	95.33
Carbonate of magnesia,	1.67
Carbonate of lime,	3.00
	100.00

An argillaceous limestone, one mile west from Damascus, yielded in one hundred parts,

Earthy residuum,	69.67
Carbonate of lime,	30.33
	100.00

The red compact limestone, No. 89, from Wady el Hareer, in Anti-Libanus, yielded in one hundred parts,

Earthy residuum,	3
Carbonate of lime,	97
	100

No. 29 was broken from the rock a few feet from the cave of Machpelah in Hebron, where Abraham was buried: a spot better identified than almost any other holy place in Palestine. One hundred parts gave,

Earthy residuum,	0.33
Carbonate of magnesia,	6.33
Carbonate of lime,	93.34
	100.00

These analyses show us, what indeed we might have expected, that the limestones under consideration have been but slightly dolomitized. That from Lebanon contains, indeed, a large proportion; but it would be desirable to know its precise location before we conclude the whole of that mountain to be as highly charged with magnesia.

I could have had but little hope of being able to refer to their true place, in the geological scale, these insulated specimens of limestone, collected by different individuals in distant lands. But through the liberal assistance of Professor Bailey, and his great skill in the use of the microscope, I am enabled to assign to a part of them, at least, a place among the rocks, with confidence. The following paragraph, from Mr. Weaver's Observations on the Discoveries of Ehrenberg, contained in the Annals of Natural History for June, 1841, did, indeed, furnish the clue to the results at which we have arrived.

" The compact limestone rocks which bound the Nile in the whole of Upper Egypt, and extend far into the Sahara or Desert, as well as the west Asiatic compact limestones in the north of Arabia, are in the mass composed of the coral animalcules (Polythalamia of Ehrenberg, the same as the Foraminifera of D'Orbigny) of the European chalk. This affords a new insight into the history of the formations of Lybia, from Syene to the Atlas, and of Arabia, from Sinai to Lebanon."

The perusal of this paragraph led Prof. Bailey to request me to send him specimens. This was done, and very soon he was so obliging as to return the following interesting results:

" I hastened," says he, " to examine microscopically the powders which you kindly sent, and obtained the following results:

" No. 136. From the Pyramid of Cheops, near Cairo: Polythalamia distinctly present, but rare.

" No. 2. Chalky limestone, west side of Anti-Libanus: Polythalamia abundant.

" No. 13. Limestone one mile west of Damascus: Polythalamia abundant.

" No. 5. Chalky limestone, Mount of Olives: Polythalamia abundant.

" No. 6. Do. Beyroot. Polyathalmia present, but not so abundant as in No. 5.

No. 30. Argillaceous limestone, river Barida, Anti-Libanus: Polythalamia abundant.

" This examination then confirms Ehrenberg's statement with regard to the presence of coral animalcules (Foraminifera of other writers) in the limestones of Arabia. His statement refers to the compact limestones, which he says are thus composed, ' from Sinai to Lebanon.' I do not see, in Weaver's abstract of Ehrenberg's views, any notice of the occurrence of these shells at Jerusalem, or Damascus; but I doubt not, that the rock at these localities forms part of the same series which was observed by Ehrenberg 'at Hamam Faraun and Tor, in the Sinaian portion of Arabia,' 'constituting hilly masses in Upper Egypt,' and 'continued eastward far into the interior of the Great Desert plain, trending eastward toward Palestine.' Damascus is a point further to the north and east than Ehrenberg mentions. How interesting the thought, that the Mount of Olives, and probably the Holy Sepulchre itself, was formed by these minute creatures, of which more than a million exist in every cubic inch of the rock!'

"Having determined the presence of these creatures in the specimens, I next endeavored to ascertain if they would afford any evidence as to the geological age of the formation from which they were taken. Ehrenberg had already referred the specimens examined by him to the epoch of the chalk, relying for the correctness of this statement on the identity of the *predominating forms* with those found in the chalk of Europe. With the forms of the English chalk, recent examinations have made me somewhat familiar; and I feel no hesitation in saying, that the specimens sent by you contain forms specifically identical; and to this statement I can add, that the *predominant* forms of the chalk marls from the vast regions of the Upper Missouri and Mississippi are also the same. As the prevailing Polythalamian forms of the tertiary epoch are *much larger* and of distinct species, need we hesitate to refer the Asiatic and American deposits to the cretaceous group? That the reference is correct in regard to the American deposits, you will remember was shown by the character of the organic remains of *other classes* of animals found by Mr. Nicollet.

"To enable you to judge of the close resemblance of the forms of Polythalamia, I have made, with the *camera lucida*, a series of comparative sketches. (Pl. XIII.) They are very imperfect, for, as the little shells are often considerably hidden by adhering calcareous particles, I found some difficulty in taking the outlines. Ehrenberg mentions *Textularia globulosa* and *Rotalia globulosa*, as among the chief constituents of chalk. Figs. 2 and 3, I drew from the most common forms, in a specimen of English chalk. I have little doubt, that fig. 3 is the *Textularia globulosa*, and I strongly suspect that fig. 1 is *Rotalia globulosa*. I, however, do not profess to be acquainted with the genera and species of the Polythalamia; but, whatever the names of figs. 2 and 3 may be, there can be no doubt of their specific *identity* with the forms shown in figs. 1, 3, 4, 5, 6, and 7, from Damascus and the Mount of Olives, Beyroot, and a missionary station on the Upper Mississippi. You will observe in the figures small spots, marked *a, a.* These were red spots found in the cells; possibly eggs. They are present both in the Asiatic and American specimens. The other dark spots, *b, b,* are air bubbles, left in the cells after spreading the specimens in Canada balsam.

"The scale of the drawings is the same for all. Fig. 6 shows $\frac{25}{100}$ of a millimetre, magnified equally with the sketches. No siliceous infusoria were found in any of the specimens."

These details seem to me to furnish a most interesting example of the triumph of science over difficulties, and to hold out great promise to geology from the microscope. The missionary, as he hurries over unexplored regions on his horse, or on his camel, breaks off a few specimens of the rocks he meets, giving them a place, perhaps, in his wardrobe;* and at length sends them to me, five thousand miles distant, with a label, merely indicating the locality. I inclose eight or ten specimens in a letter to Prof. Bailey, through the mail, so minute, that the most sagacious postmaster would not suspect their presence, and would not think them a breach of the law did he notice them. In a short time the microscope is made to reveal infinitessimal forms in these specimens, which fix their position in the geological scale of rocks, as satisfactorily as if they contained megatheroids or mastodons. In other words, the most difficult problem in geology, the identification of rocks in widely separated regions, is solved at a glance, and at the distance of five thousand miles from the only place where we should suppose it possible to solve it. If this is not a beautiful example of the magic power which science sometimes bestows upon its votaries, I know not where one may be found. In these remarks, I shall of course be understood to refer to the gentleman who has brought out these results; and not to myself,

* I have reason to know, that not a few of the specimens in my collection were conveyed in this manner hundreds of miles, over some of the roughest regions of Asia. Indeed, half a suit of clothes, thus freighted, in one instance came into my possession; and if they had been hung up, with their contents, in my cabinet, they would have furnished an interesting memento of zeal in the cause of science.

who have been merely the medium through which the specimens and results have been transmitted.

The developement of limestone in the wide region extending from Upper Egypt to the northern part of Syria, judging from the testimony of travellers, must be immense. Nearly all Palestine appears to be underlaid by it, and Lebanon and Anti-Lebanon are mainly composed of it. How much of this rock is the chalky limestone, I know not. But travellers describe this variety as occupying the surface to a considerable extent over the wide area above named. In most places its strata are horizontal, but in others highly inclined. Rev. W. M. Thomson, an American missionary, whom I have not mentioned, has given, in his journal in the Missionary Herald, an account of an excursion from Beÿroot to Aleppo; and in one place on Mount Lebanon, near Ant Elias, where he was accompanied by Mr. Hebard, he says, that the thick layers of marl, which are there "separated by thin strata of hard limerock," stand perpendicular to the horizon. (*Miss. Herald, January* 1841, *p.* 30.) M. Botta has described the rocks of Lebanon as consisting of three groups. The highest is composed of limestones of variable hardness, alternating with marls; the middle group embraces siliceous beds and nodules, with fossil shells and fishes; and the lowest group is mostly sandstone, with beds of silico-calcareous matter, iron ore, and lignite. He refers the whole formation to the chalk.

It may be presumption in me to raise a doubt as to the conclusion that the vast pile of mountains, nearly ten thousand feet high, called Lebanon and Anti-Lebanon, and indeed all the compact limestones from Syria to Syene, belong to the cretaceous group. But the exact identity of lithological characters between many of the specimens sent me by Mr. Hebard, and the lithographic limestone of the Jura, or Öolite group, from Germany, (specimens of which are laid upon the table for comparison,) cannot but excite the inquiry, whether the rock on which Jerusalem is built, (No. 422,) and Nos. 33 and 44 from Anti-Lebanon, 26 and 37 from near Damascus, 32 from the Pool of Siloa, and 45 from the rock at Hebron, in which is the cave where Abraham was buried, may not belong to the Öolite. In other words, whether both the Öolitic and the cretaceous groups do not exist in those regions. There are calcareous breccias and conglomerates, also, (Nos. 35, 43, and 47,) frequently lying above the compact limestone, and made up entirely of fragments of calcareous rock, which seem, from their great hardness, to belong to a formation older than the chalk. And, finally, Rev. Mr. Thomson, in his tour from Beyroot to Aleppo, describes Mount Cassius, somewhat west of Antioch, in the northern part of Syria, as abounding in primary rocks. Still further west, the marl had disappeared, and vast masses of serpentine took its place. At Mount Cassius, he describes serpentine, hornblende, and micaceous rocks, and a deposit of granite two hundred feet thick, resting on a talcose rock, that was found for miles uninterruptedly. This, to be sure, is a rather an unusual position for granite; but if it had been protruded through the talcose rock towards the top of the mountains, it would have been easy to mistake the mantling of the slate around the granite for an inferior position. Above the granite, he says, there rested a deposit of hornblende and mica. So that I doubt not the older crystalline rocks occur there. Again, No. 94 is limestone with talc from Beyroot; precisely such a rock as occurs in New England, in some of our oldest deposits. If, then, the oldest rocks exist in the vicinity of Lebanon, we may presume that the formations intermediate between these and the chalk will be found there, as in other parts of the world*.

If Botta is correct in placing the sandstones of Lebanon beneath the compact limestones, I acknowledge that the character of these sandstones corresponds very well to the ferruginous sandstone formation of this country, regarded as belonging to the cretaceous formation. They are, for the most part, highly ferru-

* *January* 1, 1843. Through the kindness of Prof. C. U. Shepard, I have just seen a rough section of the rocks, extending from Beyroot to Damascus, across Mount Lebanon and Anti-Lebanon, constructed by Rev. Mr. Lanneau, American Missionary at Jerusalem. He represents three principal deposits through the whole distance; namely, conglomerate at the top; beneath this, chalky limestone; and compact limestone the lowest of all. Such a position of the latter corresponds with the suggestion in the text, that it may belong to the öolite group. He places the sandstones quite high upon the mountains, above the compact limestone.

ginous, and easily crumbled down. Nos. 79, 80, 81, 82, 83, 87, 88, and 98, will convey a good idea of their character. No. 98 overlies an interesting mineral, (No. 99,) which I believe is regarded in Syria as bituminous coal. Such, indeed, I should have considered it, had I not subjected it to analysis, when I found its composition as follows, in one hundred parts:

Bitumen, or volatile matter,	68.0
Carbon,	24.4
Earthy incombustible matter,	7.6
	100.0

Now I believe that no bituminous coal, occurring in regular beds, contains near as much volatile matter as this specimen. Indeed, its composition corresponds very well with that given for asphaltum. And yet it conducted quite differently, when heated in a platinum bowl, from a specimen of true asphaltum, (No. 100,) from Gebel Es Shakh, on Mount Hermon, which is a part of Anti-Libanus. The latter specimen easily melted; but the former did not melt at all. The specimen from Hermon, however, did not differ very much in composition from the one taken from Lebanon. In 100 parts I found

Bitumen, or volatile matter,	72.6
Carbon,	14.0
Earthy residuum,	13.4
	100.0

These analyses will, I think, justify the inference, that these deposits of bitumen can have little bearing upon the question of the age of the rocks containing them; for they are probably of volcanic origin. The character of the lignites occurring in the same series, at Brumanah on Lebanon, is not different from that of common lignites, and the accompanying shales are mere friable clay, impregnated more or less with carbon. See Nos. 69, 70, 71.

None of the specimens sent me appear to be genuine chalk, but rather chalky limestones, or marls. Nor have I seen any genuine chalk described as occurring in any part of this vast cretaceous formation. The specimens sent by Mr. Hebard under the name of flint, Nos. 72 to 76, appear to be rather chert or hornstone passing into flint.

The organic remains found on Lebanon and Anti-Lebanon are considerably numerous, and quite interesting. The most so, probably, are the fossil fishes from Hakil, on Lebanon. They are found on a light-colored marl slate, resembling that of Monte Bolca, though harder, (No. 91.) They are usually rather small, and have decidedly homocercal tails, as we should expect. But I need not dwell upon them, since they have been described by Agassiz, in his *Poissons Fossiles*, and referred to the cretaceous formation. At Alich, on the same mountain, occur numerous specimens of the nuclei of at least two species of Venus (Nos. 647 to 653); also of an Isocardia, (No. 654,) perhaps the minima (*Goldfuss*, Tab. 140, fig. 18); also of an Arca (No. 655); also of a Strombus (Nos. 656, 657); also of a Rostellaria (Nos. 658, 659, 660, *Goldfuss*, Tab. 170, fig. 6); also of a Natica? (No. 661;) also of a Spatangus, (No. 662, *Goldfuss*, Tab. 46, fig. 2.) No. 40 is a Caryophyllia from Lebanon; No. 51 an Hippurites from Ain Nab, on that mountain; and No. 52 a large species of Terebra from Babda, on the same. Many of these may be new species; but I do not feel competent to decide that question without access to more numerous authorities than are at present within my reach.

The siliceous nodules occurring in the middle group of limestones of Lebanon, are often very fine and beautiful. Some of them, as Nos. 62, 63, and 334, appear externally rough, and devoid of all beauty. But, on breaking them open, they present rich geodes of crystallized quartz, with crystals of calcareous spar, sometimes implanted upon the quartz. Those which I have seen vary in size, from that of a man's fist to that of his head. From the number sent to this country, I infer that they are very abundant. Another variety consists of fine geodes of chalcedony. No. 58, which is six or eight inches in diameter, is found a little northwest of Safet, where it is very abundant. This is a region, as we shall shortly see, where volcanic action has been powerful; but whether this has any connection with the production of the chalcedony, I know not; for these geodes appear to have been formed in the limestone. Yellowish crystallized carbonate of lime appears to be common in Lebanon, having the columnar structure exhibited by Nos. 64 to 68. Near Aleppo, according to Mr. Thomson, are large beds of gypsum; and from this are obtained fine plates of selenite, such as No. 59.

I have not yet mentioned a remarkable variety of limestone, found on the west shore of the Dead Sea. It is nearly black, perfectly homogeneous and compact, and contains a large proportion of bitumen, (Nos. 77 and 145.) On this account, it admits easily of a polish, and is employed at Jerusalem for the manufacture of rosaries and other small articles. I found its composition, in one hundred parts, to be,

Bitumen,	25.00
Carbonate of lime,	68.73
Carbonate of magnesia,	0.27
Earthy residuum,	6.00
	100.00

From this analysis I draw two inferences. The first is, that if this rock can be obtained in abundance, it may prove valuable in the formation of a cement for pavements, and other purposes; having in fact a very similar composition to the artificial compound employed in that manner. The only difficulty seems to be in getting rid of the carbonic acid, as sufficient heat cannot be applied without destroying the bitumen. I have, however, no suggestion to make on the subject. My second inference is, that this limestone ought to be regarded as a mineral species, distinct from carbonate of lime. All the bituminous carbonate of lime hitherto described, except that from Dalmatia, which is probably the same as that from the Dead Sea, contains so little bitumen, that it has been supposed an unessential ingredient; but in this case, it forms a quarter part of the stone, and there can hardly be a doubt but it exists in the compound in a definite quantity. Yet, as the combining proportion of asphaltum does not seem to be ascertained, we cannot test the composition by this rule. I venture to propose it, however, as a distinct species in mineralogy. In what quantity it exists at the Dead Sea, I cannot learn, Robinson and Smith found it in descending from the promontory Ras el Feshkah to the plain, near the north end of the sea; and, in one instance, it formed the cement of pebbles, as if it had flowed in among them. But such is often the appearance of the cement of conglomerates; and the rock in that region is mostly conglomerate. I apprehend that this limestone, as well as the conglomerate which it forms, were produced at the bottom of waters abounding both in carbonate of lime and fluid bitumen. It occurs in large quantities on the west shore of the Sea of Galilee, whence several thermal springs issue; and not improbably, a careful examination of that locality might show that it is now in the course of formation, and unfold the precise mode of its production.

The compact limestone, No. 380, from Mars Hill in Athens, I analyzed, partly on account of its classic locality, and partly to see whether its composition agrees with that of the compact limestones of Western Asia. In one hundred parts, I found

Earthy residuum, ...	2.33
Carbonate of magnesia, ...	0.84
Carbonate of lime, ...	96.83
	100.00

It will be seen, by comparing the above analysis with those previously given, that it corresponds closely with that of several of the compact limestones of Palestine and Syria.

The common rock of the island of Malta, Nos. 140 and 141, very much resembles some of the chalky limestones of Syria and Palestine. But Professor Bailey could not detect in it any Polythalamian remains; and it may belong to a different geological period. The organic remains found in it, however, would place it higher rather than lower, in the scale of rocks. The large shark's tooth, No. 250, appears almost as fresh as a recent one, and probably belongs to the genus, *Carcharias*. No. 153 is a Clypeaster, five inches in diameter, mostly converted into yellowish calcareous spar. — (*Bronn's Lethæa Geognostica*, Tab. XXXVI, fig. 9.) No. 151 is a very perfect nucleus in limestone of a Cardium, or an Arca; No. 152 a similar nucleus of an Isocardia; probably the I. co., of Goldfuss, Tab. 141, fig. 2. No. 142, from the spot where St. Paul was shipwrecked, appears to be a limestone of an older date than those above described, if we may judge from its somewhat crystalline texture.

Unstratified Rocks and Volcanic Action in Syria and Palestine.

It has long been a favorite theory with many Christian writers, that the cities of Sodom and Gomorrah, Admah and Zeboim, were destroyed by a volcanic eruption; and that, indeed, the Dead Sea did not previously exist; and that formerly the river Jordan flowed into the Red Sea at Akabah. The statements of travellers, in former times especially, respecting the vicinity of the Dead Sea, have seemed in a good measure to confirm these hypotheses. The peculiar character of the waters of that sea, their entire destitution of animal life, the great depth at which that lake lies below the frowning black and naked mountains around, and the general sterility and desolation which reign there, as well as the savage character of the few wandering Bedouin Arabs who inhabit the region, all give such an impression of the penal curse which seems to rest upon it, that the minds of travellers appear to have been generally overwhelmed with awe and amazement, and rendered incapable of calm and scrutinizing observation. But within a few years past, a different set of observers have given us their reports, and none of them more trusty ones than our own countrymen, whose names have been already mentioned; and the geologist now possesses perhaps the materials for deciding some of the points above stated. The subject of volcanic action in those countries becomes, on account of its historical associations, of great interest; particularly as to the time of its occurrence.

In order to form correct opinions on these subjects, it will be necessary briefly to describe that long valley, or gulf, called *el Arabah*, extending from the Red Sea at Akabah, to the Dead Sea, and thence along the river Jordan to the mountains of Anti-Lebanon; a distance of nearly two hundred and fifty miles. Its breadth is several miles, sometimes as many as ten or twelve: but its exact depth cannot be stated, although in some parts, as along the Dead Sea, and south of it, the adjoining mountains rise above it not less than three thousand feet.

If we begin at the Red Sea at Akabah, and proceed northward through this valley, we shall find its bottom gradually rising; that is, sloping southerly for about twenty miles; and the side valleys, or Wadys, as they are termed, fall into the Arabah so as to make slightly acute angles with it on their northern sides, and obtuse angles on their southern sides: that is, they fall into the Arabah, as the branches of a river running southerly do, into its main channel. These Wadys, however, as well as the Arabah, have no streams in them except in the winter. About twenty miles north of Akabah, we reach, according to Robinson and Smith, the highest part, or watershed, of this valley between the Red Sea and the Dead Sea. Thence the slope is northerly to the latter, a distance of nearly sixty miles: and this slope is as great as it is towards the south. From these facts we might infer with confidence, that the Dead Sea must lie at a considerably lower level than the Red Sea. Barometrical observations have been made within a few years past, tending to confirm this inference. The results of different experiments with the barometer are, however, very wide apart.

Moore and Beke, in 1837, make the Dead Sea lower than the Mediterranean,	500 English feet.
Schubert, do. in 1837,	599 Paris "
Russegger and Bertou, do. in 1838,	1300 " "
Wilkie, Beadle, and Woodburn, in 1841,	1417 English feet.

The point, however, has more recently been settled by trigonomical surveys. Lieut. Symonds, of the British Royal Engineers, has in this way shown that the depression of the Dead Sea below the Mediterranean is thirteen hundred and thirty-seven feet, and that of the Sea of Tiberias eighty-four feet. (*American Biblical Repository, for July*, 1842, p. 325.) Still greater is this depression below the Red Sea; since this is said to be twenty-eight feet higher than the Mediterranean. This is a most remarkable fact, the parallel of which has not been discovered on the globe; although the Caspian Sea is said to be one hundred and eight feet below the Black Sea. As we follow the valley of the Jordan northward from its mouth, we ascend at the rate of about twenty feet in a mile to the lake of Genesareth, which is a little over sixty miles from the Dead Sea. North of this lake, the ascent of the Wady is more rapid, until it is lost among the mountains of Anti-Lebanon; though, after all, I strongly suspect the plain of Cœlo-Syria to be a continuation of the Arabah; and thus we should make its termination to be not far from the mouth of the Orontes.

I ought to have mentioned, that about ten or twelve miles south of the Dead Sea, ledges of limestone, some hundreds of feet high, curve around so as to cross the entire valley of Arabah. But a deep gorge, not less than half a mile broad, fifty miles long, and more than one hundred feet deep at its northern extremity, called Wady el Jeib, is found to cut through the limestone terrace, forming a bed for the waters of winter to descend towards the Dead Sea. I ought, also, to state, that all the lateral Wadys north of the watershed in the Arabah, tend towards the north, or in a direction opposite to those south of the watershed.

Now it is almost exclusively along the valley of the Arabah that we find the traces of ancient and recent volcanic action. Beginning at its southern extremity, we find travellers describing granite and trap rocks in the vicinity of Akabah; and Burckhardt says, that ancient volcanic craters occur in that vicinity. In going northerly, a lofty range of mountains, the mountains of ancient Edom, bounds the east side of the valley; but of their nature I know nothing till we reach Petra, where sandstone abounds; probably the new red sandstone. A little to the north, the order of strata in ascending the mountain, three thousand feet high, according to Robinson and Smith, is limestone at the base, next porphyry, forming the main body of the mountain; above this, sandstone; and at the top, limestone. Between this place and the Dead Sea, limestone is the only rock spoken of by travellers along the Wady, and it is said that the mountains all around that sea are of limestone. This is certainly the case on the west side: but those on the east side have not been so well ascertained. Irby and Mangles found fragments of granite and porphyry on the southeast shore; and Seetzen describes the mountain there as of gray sandstone. My collection is altogether wanting in specimens from the east side of the sea, except the small fragment No. 363, which seems to be siliceous slate. But I think we may safely conclude, that there does not exist on that side of the sea any decided marks of volcanic action, or they would have been noticed by such intelligent travellers as have passed over that region. Near the northwest part of the sea, however, both Mr. Hebard and Mr. Homes picked up specimens of genuine *vesicular augitic* lava, Nos. 126 and 362. The latter was obtained by Mr. Homes "from a mound once surrounded by the Dead Sea;" and I understood that gentleman to say in conversation, that this small mound was composed of similar rock. But Dr. Robinson is of opinion, that the specimens obtained by Messrs. Hebard and Homes, were mere loose fragments; and he saw no lava in place, as he passed along that side of the sea. The same is true along the Jordan, until we get as far as the Sea of Tiberias, whose shores are covered with black lava of almost every sort: Nos. 119, 120. A few miles to the northwest of that lake, and a little beyond Safed, near the village of Kadita, Mr. Hebard discovered a distinct crater, from which No. 125, whose cavities contain *hyalite*,[1] was obtained. It is between three hundred and four hundred feet in its longest diameter, and one hundred and twenty in its shortest; and about forty feet deep. (*Robinson and Smith*, vol. 3, p. 367.) Following the Jordan to its source, similar vesicular and compact lava and basalt are found, as Nos. 121 and 123, from the east side of Anti-Lebanon, will show; and I have little doubt that they may be found almost uninterruptedly through the whole extent of that chain, as far as Aleppo. Indeed, Messrs. Thomson and Beadle, in passing from Beyroot to Aleppo, found volcanic rocks in great abundance: west of Aleppo, indeed, over a space of fifty miles broad; that is, reckoning on a parallel of latitude.

On the southwest side of the Dead Sea there exists an interesting deposit of rock salt, called Kashum Usdum, from its situation near the ancient Sodom. It forms a ridge from one hundred to one hundred and fifty feet high, five miles long, covered in many places with layers of chalky limestone. This fact seems to settle its place among the formations; proving it to be connected with the cretaceous group. But if rock salt be essentially a volcanic product, as we have strong reason to believe, its position among the stratified rocks shows only how late it was protruded. The salt of Usdum, beneath the surface, has a highly crystalline structure, and is even almost limpid; as No. 423 will show. For that specimen I am indebted to Dr. Robinson; and having subjected it to chemical examination, it showed distinct traces of a sulphate, as well as of lime and magnesia; but I could not detect in it either bromine or iodine. The above ingredients exist in it in about the same proportion as in fossil rock salt generally, as I ascertained by comparative trials; and it may be regarded as a tolerably pure variety of salt. Along the western shore of the sea are several brackish springs: indeed, we know of but one of much size that is sweet, namely, that at Ain Jidy. Fragments of sulphur and nitre have also been picked up on the shore in various places.

The waters of the Dead Sea are subject to a considerable rise and fall during the year. The rains of winter and the melted snows of Anti-Lebanon produce a rise of several feet, while the long-continued heat of summer, being very intense in so deep a gulf, produces an abundant evaporation. Robinson and Smith saw decided evidence, in the drift-wood lodged along the shore, that the waters had been, during some part of the year, as many as fifteen feet higher than when they visited them. This of course produces a considerable difference in the size of the sea at different times: particularly at the south end. The valley extending southerly is for several miles very low: so that, in fact, a rise of the waters a few feet causes them to extend southerly several miles. That tract, when the waters have retired, appears like the estuary of a river, when the tide has gone out. The south end of the sea is, also, rather shallow, and there is reason to believe that a ford has existed, and perhaps does now exist, a considerable distance northerly from the end, where a remarkable peninsula extends more than half-way across it.

The very peculiar character of the Dead Sea water has long been known; and the nature of the salts, which give it so bitter and saline a taste, has been so well settled by the analysis of at least seven able chemists, that I have deemed it useless to make any trials upon it. The specimen No. 499, was probably taken not far from the mouth of the Jordan; and, therefore, has a specific gravity of only 1170; whereas the specimen analyzed by Gay Lussac had a specific gravity of 1228. The chloride of magnesium forms the predominant ingredient in this water, and hence its bitter taste. But there is a good deal of discrepancy in the per centage of the different salts, as obtained by different analysts. This may probably be explained without imputing it to errors of analysis. For if the specimen examined were taken near the mouth of a fresh-water stream, its ingredients would obviously be different from one taken at the mouth of a rill from Usdum, or one of the brackish springs along the shore. Every where, however, it contains salts enough to be fatal to animal life. Prof. Gmelin detected bromine in the specimen which he analyzed. It ought, also, to be stated here, that although the waters of the Jordan are regarded as sweet, Dr. Marcet found in them the same ingredients as in the Dead Sea, and in about the same proportion. And when we examine the hot springs on the west shore of lake Tiberias, I think we find the origin of this saline impregnation. For their taste is excessively salt and bitter, and they make deposits as they run to the lake. It is stated by the traveller Monro, that the water of these springs, or rather their deposit, was analyzed by Dr. Turner, and found to "consist chiefly of carbonate of lime with a very small proportion of muriatic salts, differing in no respect from that of the Dead Sea." The Dead Sea, however, contains no carbonate of lime; and this statement seems quite defective. Mr. Hebard found the temperature of these springs to be one hundred and forty-four degrees, Fahr. They issue from the dark bituminous limestone already described as occurring on the shore of the Dead Sea.

Dr. Marcet does not appear to have made a quantitative analysis of the waters of the Jordan. Probably it was only a qualitative analysis, and he judged of the amount of the ingredients by the eye. The following experiment of a similar kind occurred to me, which I performed. I took some of the water of the Dead Sea, No. 499, and diluted it very much with distilled water, and then put some of it in test tubes, as I did also some of the water of the Jordan, No. 554; placing the tubes side by side. I then applied chloride of barium, nitrate of silver, oxalate of ammonia, and ammoniaco-phosphate of soda, and noticed the amount of the precipitate in each pair of tubes, one of which contained the water of the Jordan and the other that of the Dead Sea diluted. The sulphates were evidently in the greatest quantity in the water of the Jordan: indeed, the test scarcely showed any in that of the Dead Sea. The chlorides were about the same in both, as was also the lime: but the magnesia was most abundant in the Dead Sea water. While this experiment, therefore, confirms the statement of Dr. Marcet, that the same ingredients are found in both these waters, it makes it doubtful whether they exist in the same proportion. But the difference admits of explanation consistently with the views that have been expressed, partly by supposing a decomposition of the sulphates of the Jordan after they are carried into the Dead Sea, and partly by the influence of the mineral springs and those from Usdum, along the shores of the sea. The waters of the Jordan, although I could not perceive in them any brackish taste, obviously contain much more saline ingredients than is usual in river water: but I have not enough of No. 499 to enable me to make a quantitative analysis.

It has long been a prevalent opinion among authors, that the Dead Sea furnishes large quantities of asphaltum. But the researches of Robinson and Smith render it probable, that whatever might have been the case in ancient times, it is rather a rare occurrence to meet with this substance in much quantity in modern days; although small fragments may be occasionally picked up along the shore. Mr. Smith's perfect knowledge of the Arabic language, gave him facilities for obtaining information among the people, possessed, I believe, by scarcely any preceding traveller except Burckhardt. The Arabs informed him that it was only after an earthquake, that large masses of bitumen were found floating in the waters. After the earthquake of 1834, a large quantity drifted ashore, near the south end of the sea; of which the Arabs brought about six thousand pounds to market. A mass like an island, or a house, rose to the surface after the earthquake of 1837; of which the inhabitants sold to the amount of about three thousand dollars. These were the only instances known to the Sheikh of the Jehâlîn, resident in that vicinity, a man fifty years old: nor did his fathers hand down to him the tradition of any other mass having been found in the sea. There is, indeed, a prevailing tradition among the Arabs, that the asphaltum exudes from the rocks on the eastern shore of the sea: but there is good reason to doubt whether such be the fact.

The character of the valley of the Jordan is an important element in our reasonings concerning volcanic action in Wady Arabah. This valley is broader in many parts than the Dead Sea; in some places as much as ten or twelve miles. It is terraced, as we find almost all the valleys in the mountainous parts of our country. In all the upper part of the valley, the terraces are two on each side of the river; that is, we ascend the immediate banks of the river and come upon the first terrace, which is frequently overflowed and covered with vegetation. We ascend a second terrace, which brings us upon a plain fifty or sixty feet above the river, and exceedingly barren. Towards the mouth of the river, is a third terrace, a few feet lower than the first above described; and both these lower terraces are covered by vegetation.

Such are the leading facts respecting the topography and geology of the Arabah. Now for the inferences.

1. There is every reason to believe that a fault runs through the entire length of this valley, from Akabah to Anti-Lebanon; and probably to the Mediterranean near Aleppo. This was the opinion of Von Buch, in reply to the inquiries of Dr. Robinson, and it will doubtless be adopted by every geologist. Along such a fault we should expect that volcanic agency would be active at various epochs. And such appears to have been the case.

2. There is no evidence that any volcanic eruption has occurred along the Arabah, or in any part of Palestine or Syria, within historic times. Lava appears to have been ejected most recently,

a little west of the Sea of Tiberias. But had the eruption taken place since the country was inhabited, some tradition of it must have been transmitted in histories that date so far back as the sacred books. The epoch of the eruption from the crater near Safed, was probably embraced in the period of extinct volcanos in other countries.

3. There is no evidence that any proper volcanic eruption has ever taken place in, or around, the Dead Sea. The mountain of rock salt at the southern extremity was probably the result of volcanic action, at least in part; but it could not have been produced by a common eruption: and even if the specimens of lava, Nos. 126 and 362, were from a rock in place, the quantity is so small as to indicate a very slight eruption. Craters and lava may yet be found in the mountains east of the sea; but if the sea itself formed the crater, it is incredible that the lava should not be found covering the western shore.

4. The present levels of the surface around the Dead Sea, and the contour of the hills and valleys generally throughout Palestine, cannot have been essentially altered since the existence of man upon the globe. Two facts, which I have stated, seem to me to establish this point beyond all reasonable doubt. The first is the character of the valley of Arabah, south of the Dead Sea. For about sixty miles it descends towards that sea; while the Wadys, that enter it from either side, trend northerly, and they are worn as deep as valleys in other parts of the world that unite to form larger valleys and streams. Now we have abundant evidence to show, that such valleys, in regions not volcanic, have not been essentially altered, except in some limited spots, within historic times. The Wady el Jeib, which is a deep gorge through the limestone cliffs towards the Dead Sea, is wider, and nearly as deep, and very much longer, than the famous gulf between lakes Erie and Ontario: and if the latter has resulted from the slow operation of the Niagara river, and must have required an immense period for its accomplishment, (and who that has examined the spot will doubt this ?) the former, also, may probably have been the result of the slower action of the winter torrents that flow through the Arabah. Nor would it be strange, if those who quote the gorge of the

Niagara in proof of the immense antiquity of the present configuration of the globe in that region, should draw a similar argument from the Wady el Jeib respecting the region around the Dead Sea.

The second argument in favor of the general position, that the region around the Dead Sea has not been essentially changed within historic times, is derived from the character of the valley of the Jordan. It is terraced almost exactly like the valleys in primary regions far removed from volcanic action. And the height of the upper terrace is about the same as on rivers of the same size in New England. Now, although there is not an entire agreement among geologists as to the mode in which this peculiar arrangement of the sides of the valley was produced, yet all agree that it must have been the result of a very slow action, and that the waters of the river must have been concerned in removing the matter which once filled the valley as high as the upper terrace. Nor do we find that these terraced valleys have been essentially changed during the memory of man; that is, the terraces remain very much as they were in the earliest periods of human history. No reason, therefore, can be given, why the valley of the Jordan should be an exception. But had the level of the country around the Dead Sea been essentially elevated or depressed, the effect must have been, either to produce a permanent inundation of the valley of the Jordan, in case of a rise of the bed of the sea; or a sinking down of the bed of the river, in case of the depression of the sea, so as to make its banks very high. Neither of these effects have taken place in that valley (with a slight exception, to be noticed below), more than in valleys in other parts of the world; and, therefore, we may infer, that no extensive change of level has occurred there within historic times.

4. Hence the theory recently proposed with much confidence, that, before the catastrophe of Sodom and Gomorrah, the river Jordan flowed through the whole of Wady Arabah, and emptied into the Red Sea at Akabah, is wholly untenable.

5. Hence, too, the supposition that the Dead Sea did not exist previous to that event, is equally without foundation.

6. Hence, likewise, the hypothesis so long in vogue, that

those cities were destroyed by a common volcanic eruption, must be given up.

7. But seventhly, there is reason to believe that, from time to time, the level of the Dead Sea has been considerably depressed by volcanic agency. In order that the sand of the upper terrace of the valley of the Jordan should be deposited, the waters of that river must have flowed over it: in other words, the Dead Sea must have once extended northerly far enough to cover that valley; for there is no barrier at the mouth of the Jordan, which might formerly have kept its waters at a higher level than those of the Dead Sea. To raise the sea above the highest terraces at the mouth of the Jordan, would not require an elevation above its present level of more than sixty feet; but as the slope of the valley southerly from the Sea of Tiberias, is, upon an average, twenty feet in the mile, it would require a rise of several hundred feet to throw back the waters over the whole of the broader part of the valley. But if we admit that the waters of the Dead Sea have suffered so much depression in comparatively recent times, still, the greater part of the work must have been accomplished previous to the existence of man upon the globe. For, as above remarked, the terraces on other rivers, and therefore those upon the Jordan, have not been very much changed since the earliest historic times; and the terraces upon the latter stream could not have been formed, until the Dead Sea had sunk so far as to leave dry the space now occupied by the terraces. Still, I think there is good reason to believe that the bottom of the Dead Sea, certainly of its southern part, may have sunk a few feet as late as the time of the destruction of the cities of the plain. That Sodom and Gomorrah were situated at the southern part of the Dead Sea, seems highly probable; because many of the ancient writers located Zoar, which was near to Sodom, on the southeast side of the present sea. But at present there is not room enough for such cities on the borders of the sea; and the soil in general is extremely sterile. Further, the scriptures speak of the vale of Siddim, *which is* not on the borders of, *but which is the salt sea*: that is, it was sea when the event alluded to (a battle, before the destruction of Sodom) was described, but dry land when it took place. An-

other fact mentioned by Robinson and Smith, renders a recent sinking of the Dead Sea somewhat probable. Towards the mouth of the Jordan there are three banks, or terraces, on each side of the river: but higher up the stream, there are only two. The lowest terrace is only a few feet below the second. Now suppose the plain at the south end of the sea to have sunk a few feet, so that the waters flowed over it: the effect would be to sink the whole sea; especially if the depression extended, as it probably would, to the entire bottom of the sea. There is another circumstance, which not only favors the idea of such a depression of the surface, and an overflow of the waters, but gives a probability to the opinion that the southern portion of the Dead Sea is the site of Sodom. It is stated in scripture, that the vale of Siddim, in which the cities of the plain were situated, was full of slime-pits; that is, *wells or fountains of asphaltum;* the same word being used as is employed in describing Babylon, whose walls we know were cemented by bitumen. No such wells occur, as we know of, any where around the Dead Sea: but, as we have seen, large masses of asphaltum have risen to the surface sometimes, as the effect of earthquakes, near the south end of that sea; and only at the south end. If springs of asphaltum exist beneath the waters, this would be a legitimate effect of the gradual accumulation of fluid bitumen, and its consolidation into asphaltum. As it is a good deal lighter than water, a violent agitation of the surface would detach it and cause it to ascend.

Now it is well known, that such effects as have been described, might be the result of volcanic agency, where there was no eruption of lava. The sudden subsidence of towns and cities on the sea-coast, from a few feet to several hundred, has been a not uncommon occurrence; as of Port Royal in Jamaica, in 1692; of Lisbon, in 1755; of Euphemia in Calabria, in 1638; and of Sindrea on the Indus, in 1819. In the latter case the sea rushed in and covered a space of two thousand square miles. Through the fissures produced by the earthquake, steam, hot water, mud, sulphur, petroleum, flames, and suffocating vapors, have several times been known to issue. We have here, then, all the ingredients and all the agency necessary to produce the destruction of the cities of the plain, according to the scriptural account, which says, that *the Lord rained upon Sodom and upon Gomorrah brimstone and fire from the Lord out of heaven.* It may be, too, that the flames, or rather the burning sulphur, would set on fire large quantities of bitumen, which had accumulated at the fountains, or pits, and thus increase and prolong the conflagration, and produce vast quantities of smoke, so as to make it not strange, that, as Abraham looked towards Sodom next morning, *the smoke of the country went up as the smoke of a furnace.* Indeed, one is reminded, by this description, of the account Kircher has left us of the destruction of Euphemia, by a similar agency. "After some time," says he, "the violent paroxysm (of the earthquake) ceasing, I stood up, and turning my eyes, to look for Euphemia, saw only a frightful black cloud. We waited till it had passed away, when nothing but a dismal and putrid lake was to be seen, where the city once stood." The sinking down of the land and the rushing in of the waters, frequently does not take place till towards the close of the earthquake, so that, in this case, there might have been time for the fire to consume the cities before the water overflowed them. It is also not at all improbable, that the ridge of rock salt, called Usdum, might at the same time have been protruded further than before, so as to become visible. In the earthquake of Cutch, a long elevated mound was thrown up, which the natives called *Ulla Bund* or the *Mound of God.* With still more propriety might Usdum receive this appellation.

I cannot adopt the opinion suggested by Robinson and Smith, Michaelis and Busching, that the combustion of the bitumen was the principal cause of the sinking of the surface below the level of the Dead Sea. For first, it would require a quantity much greater beneath the earth's surface than we have any example of; and secondly, if it were beneath the soil, as it must be to render the surface habitable, it would burn but slowly, giving sufficient time for the inhabitants to escape, which does not seem to have been the case.

8. Eighthly, if these suggestions be admitted, we can easily see how it was, that the plain, on which these cities stood, when Lot chose it for his dwelling-place, and which was well watered

and fertile, so as to be called the garden of the Lord, has, since the destruction of Sodom and Gomorrah, been one of the most desolate spots on earth. It is well known that common salt, when mixed in proper quantity with the soil, very much increases the fertility; but, if applied in too large proportion, it is eminently fatal to vegetation. If the Dead Sea existed before the catastrophe of Sodom, it would impart sufficient saltness to the surrounding region to render it very fertile. But if its limits, after that event, were much enlarged, and especially if Usdum was protruded to the surface, so as to impart saltness to most of the fountains, the excess of salt would produce the sterility which now reigns there. It so happens that we have at least three good illustrations of these views, on the western shore of the Dead Sea. At Ain Jidy is a copious fountain of fresh water, and along the banks of the stream issuing from it, is the most luxuriant growth of vegetables which Dr. Robinson ever saw. The same is true around Jericho, although the surrounding country is very sterile. A similar fertility exists along the mouths of the streams that empty into the sea on its southeast side, near the site of the ancient cities. I shall hereafter quote another example from the vicinity of a similar salt lake in Persia. In short, I do not doubt, that if a sufficient quantity of fresh-water streams were now to flow into the Dead Sea, unless they passed across Usdum itself, its shores would again become as luxuriant as Egypt.

9. Finally, we see, in the facts detailed, the principal origin of the salts contained in the Dead Sea. It is not Usdum, as some have supposed; for then common salt should be the chief ingredient. Yet doubtless Usdum increases the quantity of that substance, and so do the brackish springs along the shore have some effect. But the principal source of its peculiar qualities, I doubt not, are the hot springs on the west shore of the Sea of Tiberias, as I have already endeavored to show. These waters flow into the sea, and are evaporated by the great heat which prevails there, and thus the solution becomes condensed almost to saturation. It is seldom, it seems to me, that we can trace effects more satisfactorily to their source, than in this instance. And yet I do not recollect to have seen these springs mentioned as the source of the

impregnation of the Dead Sea, though Dr. Marcet does suggest that it may be derived from the waters of the Jordan.

In the remarks which I have made concerning the destruction of the cities of the plain, I wish not to be understood as denying the miraculous character of that catastrophe. I have inquired simply what was the agency employed by the Deity to accomplish this purpose. We know that He does not unnecessarily contravene the laws of nature, but employs natural operations, even for the accomplishment of what we might call a miracle. As to the destruction of these cities, the sacred narrative does not decide whether it was done miraculously, or otherwise. It does, indeed, impute it to the direct agency of God; but this is the manner in which every natural event is spoken of in the Bible. Hence we are at liberty to regard that catastrophe as natural or miraculous, according as we can or cannot explain it by natural operations.

There are a few facts to be added respecting the subject of drift in the countries that have now been under review; but these may with more convenience be connected with similar phenomena in countries further north and east; and therefore I shall defer them to another place.

I will close my remarks concerning Syria and Palestine, by a few statements respecting a mineral water of great historical interest, under the walls of Jerusalem, on its southeast side. It is the pool of Siloam. By the recent researches of Robinson and Smith, it is made certain that this fountain derives its waters from the fountain of the Virgin, several hundred feet higher up the valley; and there is good reason for believing that the latter is supplied, through an artificial excavation, from a well, some eighty feet deep, beneath the site of the ancient Temple of Solomon; and there is some reason to believe, that the waters of this well are derived from the fountain of Gihon, beyond the western wall of the city; and are conveyed to the temple (now the mosque of Omar) by a deep excavation. The taste of the water, which Dr. Robinson describes as "sweetish and very slightly brackish," is the same in the well and in the fountain of the Virgin, as in the pool of Siloam. Probably, also, Siloam is identical with the King's Pool, and the Pool of Bethesda, mentioned in scripture.

I am indebted for the specimen of this water, No. 555, to the Principal of the Mount Holyoke Female Seminary, who received it from Rev. Mr. Sherman, American missionary at Jerusalem.

The taste of this specimen is decidedly acid, somewhat like weak vinegar. On mixing it with a delicate purple infusion of the blue petals of a flower, it changed the color to red; and this remained unchanged for several days, precisely like a test experiment with nitric acid. It is impossible, therefore, that the acid should be the carbonic. It may, indeed, be a metallic salt, and not a free acid, which gives it its acid taste. But so decidedly acid is the taste, that I could not but suspect the specimen may have been accidentally put into a vessel containing an acid; and yet this is not probable. I regret that the small quantity of water in my possession has not allowed me to do any thing more towards its analysis, than to make a few tentative processes; and even those could not be repeated. I should not state them at all, so imperfect are they, had I ever met with any account of the ingredients in this very interesting water. I operated upon only fifty grains of the water with each reagent, and obtained the following results by a single trial.

In five hundred grains I find,

Sulphuric acid, ...	0.78 grains.
Chlorine, ...	0.49 "
Magnesia, ...	0.04 "
Lime, a very distinct trace.	

The ferro-cyanuret of potassium gave a green color to the water, and, in the course of a few hours, a blue precipitate, whence I infer, that the water is ferruginous and alkaline. (*Traité de Chimie par Berzelius*, *Tome Huitième*, p. 85. *Bruxelles*, 1840.)

Though little dependence can be placed upon the preceding results as to the proportion of the ingredients, yet they indicate, clearly enough, that Siloam must be a rather powerful mineral water. Indeed, Dr. Robinson states, that when the pool is low it is unfit for common purposes. It is much to be desired that it should receive a thorough analysis.

The second division of countries to which I wish to call the attention of the Association, embraces a few islands in the Grecian Archipelago, and some places in the western part of Asia Minor. I begin with the islands; from which nearly all my specimens were sent by Rev. Dr. Robertson and Mr. Van Lennep.

No. 369 is granite, or more probably granitic gneiss, from the summit of mount Cythnus, on the island of Delos; showing us the probable character of the nucleus of the island. But No. 191, which is the half of a stalactite, five and a half inches in diameter, sent by Mr. Paspati, indicates the presence also of limestone.

No. 384 is highly crystalline limestone from the island of Tenos; appearing precisely like highly porous lava. But the cavities are the work of some lithodomous animal; no relic of which, however, remains.

No. 378 is an epidote from the same island, and is said to be abundant there.

The specimen of red jasper, No. 393, is from the island of Egina, and occurs there abundantly in rolled nodules; and it is said, also, in limestone.

The red limestone and calcareous spar, Nos. 318 and 319, are the only specimens sent from the island of Samos.

The delicate chalcedony, shown in Nos. 335, 336, and the jasper, No. 338, are from Cyprus. The sulphate of iron, No. 300, is from the same island, and is said to be a natural product; but I suspect a mistake here. No. 635 is slaty gypsum, used for floors in Cyprus; but Mr. Van Lennep, who sent it, does not say that it is found in the island.

The principal summits in the island of Syra, according to Dr. Robertson, consist of a yellowish compact limestone, such as Nos. 381, 382 exhibit. He says, that the rocks there are mostly primary, consisting mainly of mica slate, talcose slate, and hornblende slate, as shown by Nos. 372, 373, 377. The two first specimens have *pyrope* associated with them. Beautiful *actynolite*, (No. 375) is also abundant there; and the hornblende is sometimes of a delicate blue color, (No. 376,) if the specimen be indeed hornblende. The talcose slate, No. 377, shows the talc in a somewhat indurated state, such as is common in the talcose slates formerly called transition. And the compact character of the limestone would lead to the conclusion that that rock is of a similar age. The hornblende slate, however, appears to be the oldest variety of that rock. The drusy quartz, No. 392, passing into chalcedony, or even hyalite, is said to be abundant in the mica slate of the island. The iron sand, No. 397, is cemented into a rock, and the deposit increases daily on the seashore. It appears to be a mixture of fine clay and iron, and the latter probably performs the part of a cement.

The specimens sent me by Mr. Van Lennep from the island of Rhodes, are very interesting. They consist of tertiary fossils. Says Mr. Van Lennep, "I visited Rhodes lately, and found the northern extremity of the island to contain an inestimable mine of fossil shells: some in solid rock, others in a sandy deposit, which disintegrates by the action of the atmosphere." This sand (No. 633) is made up of coarse grains of different minerals, fragments of shells, and many entire valves of shells. It has a greenish aspect, and considerably resembles green sand. The following genera of fossils exist in the collection. The species are all very different from any with which I am acquainted, and the probability is that many of them are new: but I have not the means of determining this point; and therefore leave them unnamed, with a few exceptions.

No. 621. Clypeaster, *Lam.* Species not figured in Goldfuss's Petrefacta Germaniæ.

No. 615. Pectunculus pulvinatus ? *Lamk.* Goldfuss's Petrefacta, Tab. XXXVI. fig. 5.

No. 616. Turbinolia, approaching T. cuneata of Goldfuss ; Tab. XV. fig. 9, but different.

No. 617. Natica.

No. 618. Pecten, not figured by Goldfuss.

No. 619. Dentalium.

No. 620. Pyrula.

No. 622. Turbo.

No. 623. Lutraria : Length one inch and three fourths : breadth, three inches and three fourths.

No. 624. Cerithium.

No. 625. "

No. 626. Trochus.

No. 628. Operculum of a univalve.

No. 629. Fragments of Pecten, &c. in chalky limestone.

No. 631. Turritella with Serpula.

No. 632. Serpula.

No. 634. Pectunculus polyodonta, Bronn. This large species corresponds very closely to the figure of P. polyodonta in Goldfuss's Petrefacta, Tab. CXXVI. fig. 6. It is said by that author to abound *ubicunque, in stratis marinis superioribus Germaniæ.*

We learn from Dr. Buckland, in his Anniversary Address before the London Geological Society in 1841, that most of the island of Rhodes is composed of chalk, rising in mount Atairo, to the height of four thousand feet. The chalk is partially covered by tertiary strata, from which Mr. Van Lennep's specimens were doubtless obtained.

In passing to the Asiatic continent, the region around Smyrna is the first to which I would direct the attention. This region has been described, I presume, with minuteness and accuracy by Messrs. Hamilton and Strickland, before the London Geological Society: but I have not access to their papers, or even to an abstract of them, and, therefore, I have thought it best to state the few facts within my possession; thinking it possible that some of them, obtained through Rev. H. J. Van Lennep, who is a native of Smyrna, may not be embraced in those papers.

"The country for some distance around Smyrna," says Mr. Van Lennep, "may be described, geologically, under three principal divisions. The first embraces the wide alluvial plains, which contain the rivers, and whose soil, exceedingly rich, is planted with grain or vineyards, and studded with villages, peeping at intervals through the thick olive and cypress groves. These plains extend in some directions eight or nine hours; but in others they are narrow along the seashore, and are shut in by mountains. The second division embraces various formations of stratified rocks, mostly limestone. These usually rise into hills, or mountains, generally very abrupt. One region is but a collection of high hills, sharply pointed at the top, and inclining to conical, as far as their chain-like form allows. The vegetation is quite rich on these elevations, and the olive grows wild there. The third division is volcanic, embracing many interesting rocks. A short distance from the city stands an old crater, which some have thought may have been active within historic times, though not mentioned by any author. I am more inclined to believe it one of the many which were in action before the existence of our race, and which contributed to give the earth's surface its present shape. Another fact has still more attracted my attention. The city rests in part upon a rock strongly resembling porphyritic greenstone, but distinctly stratified. In one spot I found the layers radiating from one point, and gradually assuming the general direction.

This rock is much harder than the other parts of the hill, so as to rise up above the general surface. I cannot doubt the action of fire; and yet I know not of any stratified rock of igneous origin. Much of the volcanic rock is trap, and some of it porphyry."

(Specimen No. 346, from the citadel of Smyrna, although not well characterized, appears, as Mr. Van Lennep suggests, to be porphyritic greenstone, or basalt. The division of this rock into layers, which he describes, is probably an example of pseudo-stratification; the result of concretionary structure on a large scale; an occurrence somewhat common in trap rocks.)

"Hot springs are pretty common here, of various temperatures. One of these fills a small lake, a mile from the city, which is still called the *bath of Diana.* I visited another not long ago, situated not far from Ephesus, near the sea-coast, and in sight of Samos. The ancient bathing establishment there, is still used, and the water, which contains much salt and iron, is so hot, as scarcely to admit the dipping of the hand into it. I took a bath in it, however, about noon, when the sun must have raised the thermometer to one hundred and twenty or one hundred and thirty degrees, and being necessarily exposed to its rays for several hours, I bore it much better for my scalding bath. The water flows into a plain, traversed by a small stream, and a salt marsh is produced of high rank grass, the resort of hyænas, whose growl is heard at night, as well as in the ruins of a Christian church."

The specimens sent me by Mr. Van Lennep belong chiefly to the igneous rocks. No. 345 is compact basalt, or greenstone, forming hills around Smyrna, near the sea. No. 344 is trap, with olivine, or epidote, from Cordellianæ, not far distant from the city. At Sedicui, a small village six miles from Smyrna, the trap contains numerous veins, or perhaps one very large vein, of chalcedony. (Nos. 342, 636,) connected probably with the trap in that place, is a mass of serpentine, containing bronzite, asbestus, and probably the variety of dolomite called miascite. (Nos. 347 to 352.) About two miles from Smyrna, occurs the brown pitchstone, No. 353. Brown and white opal (Nos. 354, 355) is found at Boujah, five miles southeast from the city. From the shores of the bay of Smyrna, Mr. Homes obtained the specimens Nos.

356, 357, 358, which appear to be trachytic lava and trachytic conglomerate. The trachyte occurs also at Sedicui. (Nos. 359, 360.)

The specimens of stratified rocks sent me from the vicinity of Smyrna, will not enable me to throw much light upon that part of its geology. No. 327 is clay slate. No. 326, a sort of bastard mica slate, or perhaps graywacke slate, of which No. 325 is a more distinct example. No. 328 appears as if it might be a graywacke sandstone. But I suspect limestone to be the predominant rock. Sometimes it is compact, (No. 305,) like the limestones already described from Syria and Palestine. Sometimes (Nos. 303, 304) brecciated; portions of it, usually in irregular veins, being red, from the abundance of peroxide of iron. This rock is used at Broosa as marble, and occurs on mount Olympus, near that place (Nos. 166, 167, 252); also in the island of Rhodes. (No. 42.) Some varieties of it, when weathered, have a dirty appearance. (Nos. 309, 310, 313, 314.) In one instance (No. 324 from Sedicui) we find limestone of a gray color, connected with clay slate; and the probability is, that much of it may be of the same age as that rock. In none of the specimens do I discover any trace of organic remains. The brecciated limestone, No. 308, from Sedicui, has an aspect somewhat chalky; but it is made up of hard compact fragments. Nos, 311, 312, from the same place, appear to be deposits from water, probably of comparatively recent date. No. 311, especially, shows in its delicate stratified or laminated arrangement, the marks of deposition; although it is considerably crystalline. As we might expect from the facts already stated respecting the warm springs near Smyrna, the waters generally of the springs there, deposit large quantities of carbonate of lime. No. 320 is a curious example. It is the half of an earthen-ware aqueduct, five inches in diameter, entirely filled with these deposits. Several layers of crystalline carbonate of lime appear to have been formed at first in the lower part of the pipe, and then small roots nearly filled up the passage, around which the calcareous matter accumulated, so that it exhibits precisely the appearance of a mass of petrified worms. But some of the fibres still remain. Were these all gone, the specimen might not improbably be supposed to be the relics of some animals allied to the encrinites. So rapid does this deposition take place, that pipes, such as the above, are sometimes filled in a few years. On this account they are often made more than a foot in diameter.

No. 322, is a beautiful example of that pulverulent variety of carbonate of lime, called *agaric mineral*, from a cavern near Smyrna.*

The region around the city of Broosa, in the vicinity of Mount Olympus, next claims our attention. Most of my specimens from that place were sent by Mr. Schneider; though some have been added by Mr. Homes and Mr. Van Lennep.

Hot springs are very abundant at the foot of Olympus, not far from the city. The consequence is, that tufaceous deposits are common. They are mostly calcareous, though No. 294, from the foot of Olympus, is siliceous, and was probably an aqueous deposit. Baked clay is used in the city for aqueducts, as at Smyrna, and they soon become filled with calcareous matter. "In the box," says Mr. Schneider, "you will find a specimen (Nos. 172, 173) of the earthen aqueducts of Broosa, filled up, or partly filled, by the sediment of the water. Where these pipes are in a level position, in three or four years they are completely filled. When they lie more inclined, or stand upright, it requires a longer time. The elevated platform on which the old part of the city of Broosa stands, was probably gradually formed by the numerous fountains gushing from the foot of the mountains, and leaving this deposit. On examination it is found, that the rock beneath the city, and the substance in the pipes, are of the same nature."

Nos. 187, 188, are specimens of the common rock at Broosa, and are a tufaceous, though hard and nearly compact limestone. No. 155, which is also said to be the common rock, is decided tufa. Nos. 194, 323, are calcareous tufa, broken from the curb of

* Since the preparation of the text, I have seen, in Dr. Buckland's Anniversary Address before the London Geological Society in 1841, an abstract of a paper by Mr. W. Hamilton, read before that Society, on the Geology of Smyrna and vicinity. The rocks which he describes, correspond essentially to those mentioned in the text. Mr. Strickland describes a cretaceous limestone near Smyrna with hippurites. (*Address*, p. 42.)

one of the hot springs at Broosa, used for supplying warm baths. On the label accompanying the specimens, Mr. Schneider remarks, that "the spring gushes hot from the foot of the mountain, and warms the bath sufficiently without artificial heat. At the orifice it is hot enough to boil an egg (not very hard) in five minutes. The bath is called Kükürtlü, or sulphureous bath, because its waters are strongly impregnated with sulphureted hydrogen. When a piece of the earth is broken off, the vacancy is soon filled up. Very near this spring are two others, whose waters are materially different from that which supplies Kükürtlü. I intended to have bottled some of these waters and sent them to you, that you might analyze them if you wished; but forgot it till too late. Some travellers have attempted to perform this work; but I fear it has not been done well."

No. 260 is a deposit of some interest from one of these springs. Its lower part is calcareous tufa, more crystalline than usual. Upon this is a deposit, nearly an inch thick, highly porous and somewhat crystalline, which, on boiling fifteen minutes, with twice its weight of carbonate of soda, was converted into carbonate of lime; from whence I infer the deposit to be sulphate of lime. Upon the sulphate of lime is a slight incrustation of sulphur, which Mr. Schneider says was originally "a crop of beautiful sulphur crystals."

No. 646 is calcareous tufa from the Castle Hill of Broosa, which is penetrated by cavities having the form of vegetables, around which the tufa was deposited.

Other varieties of limestone occur in the vicinity of Broosa; one of which, the brecciated, with red veins, has been already described (No. 252), as found near the foot of Olympus. At seven or eight miles distance from the city, is a mountain, where there exists the compact limestone, No. 261. In ascending Olympus different limestones occur; and at the height of six hundred feet, are several varieties of rock, (Nos. 159 to 163,) which, with some hesitation, I refer to sandstone and conglomerate. They are quarried for millstones, and Nos. 159, 160, 163, appear to be a fine-grained, highly siliceous sandstone: yet it is possible that they may be a quartzose variety of gneiss, in which the feldspar has been more or less decomposed. An example of this sort I have described as occurring in Berkshire county in Massachusetts, in my Final Report on the geology of that State. In Massachusetts, also, this rock is used for millstones. At Broosa the rock is sometimes highly cavernous, from the existence of small segregated veins, between which some highly ferruginous substance has nearly disappeared. The cells thus produced, take the form of a cube or a parallelopiped; and, in some of the specimens, the whole mass appears as if it might be a vegetable relic. (Nos. 160, 163.) A similar appearance exists in some varieties of the limestone found near the foot of Olympus. (No. 166, from ruins in Broosa.) But I doubt, in either case, whether genuine vegetable remains exist. This sandstone, or perhaps metamorphic gneiss, passes sometimes into a decided conglomerate; as Nos. 161, 162. The imbedded pebbles are quartz, hornstone, and jasper. In the same rock occur fine tabular crystals of sulphate of baryta, with dihedral summits, and of a color inclining to wine yellow, (No. 165.) A quartzose conglomerate exists, also, in connection with the pseudo-burrhstone in Massachusetts, above alluded to; and upon the whole the resemblance between the two cases is rather strong.

The chain of Olympus reaches its greatest height, of nine thousand one hundred feet, not far from Broosa. "This chain," says Mr. Van Lennep, "advances from the eastward, rises to its loftiest summit, and stops suddenly short. The earlier rocks it has displaced form a gradual slope, which extend a mile or two beyond Broosa westward." (Mr. Van Lennep here introduces a section, showing the rocks on this slope in the following order: first, primary or early secondary limestone: secondly, calcareous tufa with vegetable impressions: thirdly, limestone and argillaceous slate: fourthly, rocks of igneous origin: fifthly, early secondary limestone and argillaceous slate: sixthly, limestone conglomerate. He then proceeds to notice the rocks north of Olympus.) "The chain runs east and west. Immediately north of it, lie generally rich alluvial plains. These are sometimes interrupted by limestone hills. Beyond the plains are also hills of the same limestone. Further on towards Ghunlik, the ancient

Rios, are hills of argillaceous slate, containing much limestone, which make an excellent soil for wheat. Towards the lake of Nice, there are hills of porphyritic trap with some columnar formations."

Messrs. Hebard, Van Lennep, and Schneider, all agree, that the principal body of Olympus is gneiss, with occasional beds of crystalline limestone. The specimens which they have sent, fully sustain this opinion. Nos. 271 to 278 are distinct gneiss: No. 279 is gneiss passing into hornblende slate, and Nos. 280 to 284 are hornblende slate. Nos. 285 to 288 are varieties of mica slate from near the base of the mountain. The limpid quartz, No. 289, and the quartz rock, No. 290, are from the same place. The massive garnet, No. 291, is from near the summit of the mountain, where it is said to be very abundant. The limestone associated with the above rocks is usually white and granular, as shown in Nos. 156, 157, 158, and 246. The latter is from the summit, and resembles dolomite. But on analysis I find the following to be its composition.

Earthy residuum, ...	0.67
Carbonate of lime, ...	99.33
	100.

This limestone is highly fetid, a fact which I have noticed often in some of the highly crystalline limestones associated with gneiss in this country. No. 243 is columnar calcareous spar, obtained by Mr. Hebard from the top of Olympus.

Towards the foot of Olympus is a deep ravine in the compact limestone, where extensive tufaceous deposits have taken place, and large quantities of stalactites, stalagmites, and especially crystals of calcareous spar, are seen lining the mural faces of the rock and the numerous small caverns existing there. Nos. 239, 242, and 641, are examples of the stalactites, and No. 240 is a singular and unusual form of stalagmitic deposit, which I have sometimes seen going on in water at the bottom of a limestone cavern. Nos. 230 to 238, and 239, 240, are examples of the varieties of crystallized calcareous spar from this spot. The crystals, so far as my specimens show, all assume the form of extremely acute rhomboids. Their acute trihedral summits are sometimes replaced by a much more obtuse trihedral summit, forming a doubly trihedral termination. But it is difficult to give a definite idea of these crystals without figures. Those with simple trihedral summits correspond nearly to Figs. 101, 106, and 108, of Shepard's Mineralogy, Vol. I. p. 99, 100. But I have found it impossible to measure the obliquity of the rhomboid, because only the terminating pyramid projects from the surface.

No. 241 is a small stalactite formed at Broosa by water dripping from an aqueduct. It is scarcely at all crystalline, but consists of thin successive cylinders of soft limestone enveloping one another, and apparently cohering so little that one might be slipped out of the other, were they not somewhat irregular.

Nos. 176, 177, 184, and 185, were obtained by Messrs. Schneider and Powers, on an excursion from Broosa to Kutaieh. They appear to be metamorphic slates, and indicate the powerful action of heat. No. 171 appears, also, to be metamorphic, and contains a large per centum of red oxide of iron. No. 170 is a beautiful mixture of red and white opal, from the plain of Kutaieh, near a ridge of the Taurus.

Nos. 178 and 295 are vesicular lava from the *Katakekaumene*, or *Burnt District* of the Greeks, described by Strabo. It lies east of Smyrna, near the ancient Philadelphia. Mr. Schneider says, "these black stones extend over a distance of twenty or thirty miles, and the whole has the appearance of a stream of lava, not very wide, suddenly cooled." No. 362 is compact lava from the same district, sent me by Mr. Homes.*

In 1841 Mr. Van Lennep took an excursion by land through a part of Asia Minor, thence across the Sea of Marmora into Roumelia, as far, I believe, as Adrianople. His account of the rocks of Mount Olympus and northerly to the lake of Nice, has already been presented. Some additional facts will now be given.

* Mr. W. J. Hamilton, in a paper read two or three years ago to the London Geological Society, describes three periods of eruption in the Katakekaumene, all of them previous to historical dates. (Dr. Buckland's *Anniversary Address before the Geological Society, February*, 1840, p. 37.)

"My tour extended both into Asia and Europe, and I formed a general idea of the geology of the regions through which I passed, so as to be able to give it in a few words. From the chains of the Olympus to the great Balkan in Roumelia, there is a regular series of rocks. The Marmora produces no changes, nor any difficulty in the study of the formations, especially as the Princes' Islands continue the gradation of the series."

After describing the rocks of Olympus and northward, as previously given, Mr. Van Lennep adds:

"At Constantinople, and along the western side of the Marmora, the prevailing rock is secondary limestone, full of shells of various species, bivalve and univalve. (No. 627 is an example of the former.) So far as I know, all the other rocks are of volcanic origin. And similar to the above description are all the rocks of Roumelia, so far as I have been."

Mr. Van Lennep adds, in respect to a region southeast of Smyrna, in the ancient Pamphylia, some statements that may be interesting, though derived from European travellers. He was informed, that,

"In Pamphylia, there is a gradation from the seashore, to a distance of several days' journey inland, of shells, gryphites, corals, &c. Large plains are entirely underlaid by fossil coral, while the coast westward is entirely composed of primary limestone. Another traveller brought me, a few days ago, oysters, pectens, &c., which he found in an elevated plain six days' journey from Smyrna in a southeast direction. I hope, myself, to take a trip next fall from Macri to Satalia along the southern coast of Asia Minor; and, while I attend principally to missionary labors, I shall endeavor not to forget the interests of science."

No. 471 is a specimen of genuine bituminous coal, obtained by Mr. Perkins at Heraclea, some seventy or eighty miles east of Constantinople, on the south shore of the Black Sea. I am told it occurs there in considerable quantity, and if it does, it must be invaluable, both from its proximity to the capital, and its excellent quality. An analysis of one hundred parts gave the following results.

Earthy matter,	5.8
Volatile matter,	31.8
Carbon,	62.4
	100.

No. 642 was obtained by Mr. Van Lennep from the western banks of the Bosphorus, and appears to be coal identical almost with that from Heraclea. The lignite, No. 643, is from the same shore. On the shores of the Black Sea, in Thrace, is an interesting and extensive deposit of lignite. Nos. 329, 330, and 412, are from the Thracian bed, and for them I am indebted to Messrs. Homes and Hamlin. The former gentleman says, that the bed is five miles long, and from three to ten feet thick. The latter has sent specimens of the clay and limestone which contain the lignite. No. 409 is a friable clay, with traces of plants: No. 410 is a more compact clay, somewhat calcareous; and No. 411 is a limestone partly Öolitic and partly made up of small rounded grains of limestone. There can hardly be a doubt, from these specimens, that this lignite is in a tertiary formation, about which more, we hope, may ere long be brought to light. In the vicinity of the lignite bed, is a protrusion of trap, as appears from No. 421, which is a concretion of trap. From the manner in which the "lignite strata" dip from this trap, as described by Mr. Hamlin, I suspect its protrusion to be more recent than the deposition of the tertiary formation.

Some other specimens have been transmitted by Mr. Hamlin from the vicinity of Constantinople, which deserve notice. No. 400 is black limestone, from the Sutton black marble quarry, near the quarantine grounds, almost five miles up the Bosphorus from Constantinople, on the Asiatic side. No. 408 is rich pyritous copper, from the copper-mine called the Sutton mine on the Bosphorus, near the Black Sea, above Bugukdere. From the specimens of gray sandstone, Nos. 404, 405, 406, obtained in the vicinity of the mine, and the statement of Mr. Hamlin, that this is the predominant formation in that region, I suspect the copper to be connected, as it often is in other parts of the world, with new red sandstone. Nos. 415 and 416 are pebbles of siliceous slate: No. 417 of flint; and Nos. 418, 419, of jasper, from a vast pile of pebbles on the shore of the Black Sea, near the lignite bed.

Numerous specimens in my collection were obtained from ancient ruins. They consist of elegant marbles, porphyry, granite, &c., interesting as individual specimens, and to the antiquary; but since their original localities are not designated, I have thought it would be useless to the geologist to describe them. Many specimens of little importance, obtained from the rocks in place, I pass also in silence.

The third extensive region of which I wish to give some geological notices, embraces the ancient Armenia and a part of Persia and Georgia. For my specimens and descriptions I am indebted to Rev. Justin Perkins, except two or three specimens from Rev. J. L. Merrick. Mr. Perkins is now on a visit to this country, in company with Mar Yohannan, an intelligent bishop of the Nestorian church; and I have had full opportunity to converse with them respecting the points to which I wish to call the attention of this meeting. I cannot but bear testimony to the strong desire and effort manifested by Mr. Perkins, to collect and transmit specimens and information respecting the countries through which he has travelled. In his journey, for instance, from Persia to the Black Sea, a distance of seven hundred miles, over a very rough country, on horseback, and with his wife in feeble health, he contrived to bring along not less than seventy-five specimens of rocks and mineral waters; and in one instance brought on a fever by his efforts to climb a high peak of the Ararat range, in order to break a specimen from its summit. His route lay from the city of Oroomiah, on the shore of a large lake of the same name, through Khoy, thence to Bayazeed, near the west foot of Mount Ararat; thence to Erzeroum;

thence to Baiboot; and thence to Trebizond. I shall reverse this order in giving an account of the specimens.

An examination of the specimens and the statements of Mr. Perkins, establishes the fact, that limestone is the prevailing rock on this route; forming even the high mountain chains that are crossed. The greater part of it is a dull compact rock, which I suspect to be older than the cretaceous formation of Egypt and Palestine, chiefly because Prof. Bailey could detect in none of the specimens Polythalamian remains, like those of the chalk, or indeed any others. Occasionally, the specimens are chalky and marly, like those from Palestine; as No. 426, from Hassan Aillah and Erzeroum, and No. 445 from Baiboot. In short, I cannot doubt that nearly all the specimens belong to the fossiliferous rocks, and probably to the older varieties. Mr. Perkins also says, that while most of "the ranges of mountains between Trebizond and Erzeroum are soft limestone, here and there a naked granite peak peers above the general surface in sublime sterility." He did not, however, bring along any specimens of this granite.

It will be perceived, that the route of Mr. Perkins crosses, toward its eastern part, that broad tract of country, which, extending from the Azore Islands to the Caspian Sea, exhibits many traces of recent and extinct volcanic action. We see the evidence of this in many of the specimens, and in the mineral springs, some of them thermal, that occur in abundance.

The specimens No. 472, 473, of the rocks usually employed for purposes of construction in Trebizond, appear to be trachyte, with imbedded crystals of hornblende, though they approach certain aggregates sometimes found with the primary rocks. Another evidence of the igneous origin of the rocks around that city, presents itself in specimens No. 489 to 493, picked up on the shore of the Black Sea at that place. They consist of chalcedony, carnelian, agate, amygdaloid, &c., which must have come from rocks of igneous origin. No. 425 is another curious illustration of the same fact. For, if I mistake not, it is almost entirely composed of grains of olivine, a mineral abundant in basalt and lava. The rock containing it must be in large quantity somewhere in the vicinity, to produce enough to be gathered as sand upon the shore.

Still another confirmation of the same views, is found in numerous mineral springs which occur in the vicinity of Trebizond, upon the mountain ridges, though these do not necessarily indicate any very recent volcanic agency. Nos. 497, 498 are specimens of two of these springs; the latter twelve miles southwest from the city, and the other seven miles to the southeast. These waters are used by the inhabitants, especially the English and Americans of that city; and, if my analysis is correct, one of them at least may lay claim to a high character. I ought to say, however, that as I received these specimens only about six weeks ago, it has been impossible to go into all those minute details of analysis that would have been desirable. My results, however, may be of some service.

No. 498 belongs to the class of simple carbonated waters. The amount of free carbonic acid and of the earthy carbonates held in solution by this acid, was obtained by the method recommended by Berzelius, in his *Traité de Chimie*, by distilling the gas into lime-water. The amount of earthy carbonates and the other solid ingredients was so small, that I thought it useless to separate them; though they must somewhat increase the value of the water. Bromine I detected by the chlorine test, as recommended by Dr. Schweitzer, in his analysis of sea water. The carbonic acid must of course be less than exists in the water as it issues from the earth. I could detect no difference between the specific gravity of this and common water.

A wine pint of the water contains as follows:

Carbonic acid, ...	10.9 cubic inches.
Earthy carbonates, ...	0.5 grain.
Chlorides of sodium, of calcium, of magnesium, and a bromide, . . .	0.5 grain.

This spring may undoubtedly be of some service in a medical point of view, especially as it contains the powerful ingredient bromine, although I could not detect iodine in it. But the other spring, No. 497, is much more powerful. Indeed, if I mistake not, it ranks among the best sulphureted waters known, though I did not find in it either iodine or bromine.

Specific gravity, ...	1.002

In a wine pint of the water I find,

Carbonic acid,	29.55	cub. inches.
Sulphureted hydrogen,	2.00	" "
Carbonate of lime,	2.67	grains.
Carbonate of magnesia,	1.44	"
Sulphate of soda,	2.24	"
Chloride of sodium,	3.25	"

Between Trebizond and Erzeroum, Mr. Perkins met with two springs similar to those above described.

" One of these springs," says he, " is situated about thirty miles east of Baiboot, in ancient Armenia, on a tributary of the river Joroke, about two miles above the junction of the tributary with the main stream. Around the spring a conical mound of limestone rock has been formed, (of which Nos. 459, 460, and 461 are examples,) by deposits from the water. I observed partially petrified matter hanging upon the spires of grass in the little rill running down from the spring. It was of the consistence of jelly, and seemed to be gradually hardening, as the water ran through it impregnated with limestone."

" The other spring is about twenty-five miles west of Baiboot, in the eastern extremity of ancient Pontus, on the Madden road, and about three miles above the point where this road leaves the Gumush Khan road. It is a ravine, about forty feet below the road, on the margin of a fresh-water stream. It is about three feet deep, and of nearly the same width; and its boiling and effervescence are so strong, that it attracted my attention as I was passing in the road. I had no previous knowledge of its existence, nor am I aware that it has been observed by any European traveller. I dismounted and went down to the spring, and was surprised to find another of a similar character, a few feet above, on the opposite side of the same stream, whose water, instead of rising to the surface of the ground, flowed through a lateral orifice into the brook. Both are so near this brook, that the water is carried away before it has opportunity to leave limestone deposits. The water tasted very much like that of the spring first named."

That the spring last mentioned above, deposits tufa to some extent, although a mound of it is not formed, appears from specimen No. 434, which was obtained at that place. The limestone there, also, from which the spring issues, (No. 433,) is almost exactly similar to the rock from which the spring thirty miles east of Baiboot issues (No. 462). These specimens will evidently give a good idea of the most common limestone along most of the route from Trebizond to Erzeroum. No. 476 is a distinct specimen of the older variety of argillaceous slate, from the vicinity of the spring, thirty miles east of Baiboot. It is tortuous and plumbaginous.

The temperature of the springs above described, Mr. Perkins did not ascertain, but thinks it was rather higher than that of the common springs of the country. The water tasted like that from a soda fountain, and both in appearance and taste resembles the spring on the east side of the lake Oroomiah, in which is deposited the famous Tabreez marble, or alabaster.

In passing from Baiboot to Erzeroum, twelve miles before reaching the latter city, and at Eleeja, there occurs a hot spring, whose temperature Mr. Perkins ascertained to be ninety-three degrees of Fahrenheit. Twenty-four miles east of Erzeroum, at Hassan Calleh, is another, whose temperature is ninety-six degrees. No. 463 is a specimen of the compact limestone from which the spring at Eleeja issues; and Nos. 464 and 465 are fine conglomerates, whose abundant calcareous cement is a deposit from this spring. When we reach the vicinity of lake Oroomiah in Persia, many other interesting mineral springs occur. But their nature and geological situation will be better understood after giving some general account of the rocks in that region, and of the lake itself. Previously, however, let us go back upon the route to Trebizond and notice a few more specimens.

No. 426 is a specimen of soft limestone, such as occurs all the way between Baiboot and Erzeroum; and, indeed, still further northwest than the former city; so as to make a distance certainly of one hundred miles. If it do not belong to the chalk formation, it may be tertiary. But Prof. Bailey found in it no cretaceous Foraminifera. It is associated at Baiboot with a compact limestone, Nos. 427, 428; and passes into a sort of calcareous sandstone, Nos. 431 and 432, which form the common building-stone of that place. At Madden, in Pontus, the building-stone is a gray lithographic limestone, No. 485. At Erzeroum, a beautiful gypseous alabaster, No. 487, is burnt and used as a substitute for limestone. It is quarried on the western branch of the Euphrates, at Aih Kelly, from twenty-five to thirty miles west of Erzeroum. It appears to be as beautiful and well adapted for ornamental purposes as any that is used for vases, &c., in Italy.

No. 484 is from the top of the first mountain ridge crossed in going from Erzeroum to Trebizond. It appears to be compact feldspar, from the ease with which it fuses, and is said to make up most of the mountain, except now and then a granite peak.

No. 435 is a pebble of siliceous slate, from the bed of the western branch of the Euphrates. No. 477 is compact limestone from Javislik, twenty-five miles south of Trebizond. No. 479 is a concretionary mass of trap, or lava, from the same place; and No. 478 a trap tufa, or breccia, made up of angular fragments of trap. Nos. 480 and 481, appear to be trap, with a stain of copper ore, from a high summit not far from Madden, where the Black Sea is just visible, in going toward Trebizond. In Madden is a silver mine, wrought by Greeks; and No. 488 is a specimen of the ore. The trap specimens just named were obtained not more than a few miles from this spot. No. 457 is from the declivity just above the mine, and seems, so far as we can judge from its lithological characters, to be graywacke slate. From these facts, then, we draw these probable conclusions: first, that this silver mine is in graywacke slate; and, secondly, that igneous agency has been in operation not far distant. This mine is fifty miles southeast of Trebizond, and thirty-five miles northwest of Erzeroum.

Nos. 436 and 437 are fine specimens of pyritous copper, from a mine fifteen miles east of Baiboot. The mine is wrought by Greeks, and it is said to be the most easterly point in Asia where that people are to be found. A little east of the copper mine is a very extensive deposit of dark serpentine, shown in No. 456. This locality is on the second mountain ridge west of Erzeroum, near forty miles from that city, and four miles west of the village of Roshapana.

A high range of mountains is shown on the best maps, extending westerly from Mount Ararat, and is called the Ararat range. From one of the highest peaks of this range, where it is crossed by the short Erzeroum road to Oroomiah, was taken No. 466; which is compact limestone, with a vein more crystalline. No. 467 was probably broken from one of these veins, and seems to be argentine. An analysis gave the following results in one hundred parts.

Earthy residuum, (?)	1
Carbonate of lime,	99
	100

East of Erzeroum, between that place and Hassan Calleh, is found the argillaceous limestone, or as I rather presume it to be, the marl, No. 445. Limestone continues nearly to the foot of Ararat. No. 444 is a hard porous variety, appearing as if deposited from a spring, from a branch of the Euphrates, eight miles west of Diadeen. No. 443 is a reddish compact limestone, from a point east of Diadeen, and twenty miles from Ararat. Near the west foot of that mountain, occurs the dark-colored limestone, No. 441. In the same vicinity was picked up the petrified coral, No. 440. Much further from the mountain, however, distinct vesicular lava, both in rolled pieces and in hummocks, is abundant. No. 442 appears like recent lava, and was found near the convent of Utch Kelasia, thirty miles west of Ararat. Nos. 438 and 439 are similar lava from Bayazeed, near the west foot of the mountain. One of these has upon it a coating of carbonate of lime. No. 229 was taken by Mr. Perkins from the foot of the mountain on its eastern side, several years ago, when he first entered Persia. It has an aspect even more like recent lava, than the specimens on the west side. Indeed, all the specimens confirm, if it needed confirmation, the statement of Prof. Parrot and others, that Ararat is made up of volcanic matter. Some travellers have even described craters, from whence eruptions have some time or other proceeded. But there is good reason to believe, that no eruption has taken place since the commencement of human history. Sir Robert Ker Porter says, that a register has been kept for eight hundred years at the convent of

Etchmiazren, of the state of the mountain, and that no eruption has occurred. Had one taken place even earlier, it is hardly possible that some account of it should not have been preserved. We may infer, therefore, that this mountain is to be reckoned as an extinct volcano.

As it is generally understood, that on this mountain the ark of Noah rested, it is not strange that a deep interest should be felt in every thing relating to it. It is an article in the creed of the Armenian church, that no one can ever reach its summit, where that nation suppose a piece of the ark still remains. Hence the inhabitants of that whole region still persist in denying that Prof. Parrot has ascended it. This is not so strange as it respects the Armenians; although Parrot was accompanied by a deacon of that church, and since that time a young man, Mr. Antonomoff, holding office in Armenia, has ascended the mountain. This was in 1834, and Parrot's ascent took place in 1829. But it is not so easily explained why the Musselmen, and even the English gentlemen who have resided of late in Tabreez, Erzeroum, &c. have all refused to believe that its summit has been reached.

This mountain has two principal summits, the Great and Little Ararat; the former seventeen thousand seven hundred feet above the sea, and the latter three thousand feet less. The highest peak is, of course, always covered with snow; but it disappears usually from the lower summit in the summer. As this mountain rises abruptly fourteen thousand feet above the vast plain on its north side, it forms one of the most magnificent objects which can be imagined. Mr. Perkins has now passed five times along its western side, and once along its eastern side, where runs the Aras, or ancient Araxes.

In describing Ararat as it appeared from the east side, or looking towards the northwest, Mr. Perkins says:

"We had near, advantageous, and delightful views of Mount Ararat, on our way to Persia. It is altogether unique in its appearance, and a very beautiful as well as most impressively sublime object. We saw its towering summit several days before we reached the mountain, overtopping all other mountains far and near. When within about sixty miles of it, we had our first distinct view of the whole mountain; and so lofty is it, that it seemed within eight or ten miles of us. Our nearest view was at the village of Khorvirab, about two miles from the base. The river Aras (the ancient Araxes) rolled between us and the mountain. The higher Ararat is almost a perfect cone. The upper part, about one third of the whole, is covered with eternal snow. The thermometer (Fahr.) ranged from ninety-five to one hundred and five degrees, when we passed it, August 11 and 12; and yet the scorching sun, under which we almost melted, seemed to make not the least impression on the hoary shroud of Ararat. The snow on its top and sides appeared of immense depth, and perfectly smooth, as though never broken or ruffled by the track of man, beast, or bird. On the lower Ararat, when we passed it, the snow lay only in patches."

"An immense plain, at least fifty miles in length, and from fifteen to twenty miles in breadth, perfectly level, and extremely fertile, stretches along the north and east sides of the mountain. At the northeast extremity of this plain is the city of Erivan; and twelve miles to the west, Etchmiazren, the celebrated Armenian convent, and the ecclesiastical metropolis of that nation. Around this plain are mountains, hanging in broken irregular piles, and indicating terrible convulsions in order to bring them into their present forms. At a distance they appear like ledges of lava; but, as you approach them, you generally find that their volcanic aspect is the effect of their naked exposure to the scorching sun."

"The physical features of the north of Persia," says Mr. Perkins, in another connexion, "are rather peculiar. There is no undulating land, or almost none. The country is divided into flat plains or valleys, surrounded and intersected by precipitous craggy mountains and ridges. The plains are very large and level. They are also extremely fertile.

"The western side of Mount Ararat presents a very different aspect from the eastern. It is less steep, symmetrical, and beautiful; but equally grand and imposing. About the southwestern base of this mountain, the surface of the ground, to the distance of fifteen or twenty miles, is rugged, and covered with stones from the size of a goose-egg to that of a man's head, which give strong indication of having been in a state of partial fusion."

I ought not, in this place, to omit a reference to the specimen of obsidian, No. 219, picked up on the road from Erzeroum to Georgia. Mr. Perkins states, that he found it on the table-land north of Ararat, as he passed easterly over a space not less than one hundred miles. This, among other facts, shows how extensively the volcanic agency, which threw up that mountain, reached around it. I would here suggest, although it may be mere conjecture, that, from an examination of the mountain ranges on the best maps, I suspect Ararat to stand at the point of intersection of two long lines of fracture, one running nearly north and south, and the other east and west. At such a point we should expect, if any where, the protrusion of melted matter.

As we might expect, Ararat and the surrounding country are quite subject to earthquakes. Tabreez, it is said, was destroyed some generations since; but the most recent event of this kind at Ararat possesses considerable geological interest. In a letter, dated Oroomiah, November 6th, 1840, Mr. Perkins says:

"We have had two earthquakes here in the course of the past summer. The first was very severe, in the vicinity of Ararat. Some parts of the towns of Erivan and Nakchevan were destroyed, and a village immediately at the base of Ararat is said to have been nearly buried by the masses of earth and rocks, that were shaken down from the mountain. The vast accumulation of snow, which had been increasing on the top of the mountain for so many generations, was broken into pieces, and parts of it shaken down the sides of the mountain, in such immense quantities, that, it being midsummer, and the snow descending into the warm region, and suddenly melting, torrents of water came rolling down the remainder of the mountain, and flooded the plain at some distance from its base."

An extract from a Russian Gazette, prepared by an officer in the vicinity, confirms these statements, and adds many details. The first shock occurred June 20th, before sunset, and precipitated an avalanche of snow, ice, and rocks, which "swept away the monastery of St. James, and destroyed a village at the base of the mountain. At seven o'clock, P. M. of the same day, three thousand one hundred and fifty-seven houses were destroyed by an earthquake, and thirty-three men and two hundred and fifty-three cattle were destroyed. On the 24th of the same month, a second more terrible avalanche descended from Ararat, and spread over the surrounding country to the distance of fourteen miles, destroying many houses in several villages." These statements were also confirmed to Mr. Perkins by the Emeer Mirzam, commander-in-chief of the Persian army, who happened to be in the vicinity of Ararat at the time.

The next spot of geological interest to which I wish to call the attention of the Association, is the lake of Oroomiah, in the northwest part of Persia, and nearly one hundred and fifty miles southeasterly from Ararat. Its length is full eighty miles, and its breadth in some places thirty miles. Next to the Dead Sea, its waters are more highly impregnated with salts than any that have yet been analyzed. Like the Dead Sea, it has no outlet; but instead of being depressed below the level of the ocean, like the Dead Sea, it is probably not far from four thousand feet above the Black Sea. The city of Tabreez is situated on its eastern shore, not far from twenty miles distant, and gentlemen connected with the English embassy there, have determined, barometrically, that that city is about four thousand feet higher than the Black Sea; and Tabreez stands nearly on the same level with lake Oroomiah. Another fact renders these statements probable. By looking at a good map of that region, we shall see that only a few short streams flow into the lake, while several other streams take their rise almost in the same place, and run a vastly longer course, some of them, as the Aras, for instance, into the Caspian Sea; and others, as some tributaries of the Tigris, into the Persian Gulf. Now unless those which fall into the lake have a much more rapid descent than the others, and Mr. Perkins informs me they have not, the lake must lie at a much higher level than the Caspian Sea, or the Persian Gulf. But we know that the former is only one hundred and eight feet lower than the Black Sea; and hence Oroomiah must be much above it.

The specific gravity of the water of this lake I find to be 1155, which is a mean of several trials with the hydrometer, and by weighing a portion of the water.

1593.6 grains were evaporated, and left a residuum of salts equal to 325.5 grains; which, in 500 grains, would be 102.1 grains.

I have met with no analysis of the water of this lake, except one by Dr. Marcet; and, as he possessed but a very small quantity of it, I thought it desirable to repeat the process.

In five hundred grains of the water, I find

	Grains.
Chloride of calcium,	0.74
Chloride of magnesium,	5.76
Chloride of sodium,	90.58
Sulphate of soda,	5.67
	102.75
Amount of salts by evaporation in 500 grains,	102.10
Excess,	.65

This excess is of course to be imputed to errors of analysis. Had time permitted, I should have repeated the process more frequently than I have done. Dr. Marcet gives the result of his analysis of five hundred grains by merely stating the precipitates produced by certain reagents, as follows:

	Grains.
Muriate of silver,	111.5
Sulphate of barytes,	66.0
Phosphate of magnesia,	10.5

I have not reduced the above analysis so as to compare it accurately with my own. But it is obvious to inspection, that he found considerably more sulphuric acid in this water than I did. I ought to mention a fact, however, that may account for this difference, without imputing it to errors of analysis. When I first received the water, it was so strongly impregnated with sulphureted hydrogen as to tarnish silver at once. Now must not this gas have resulted from the decomposition of the sulphates in the water? If so, as Dr. Marcet mentions nothing of the kind, it may explain the smaller quantity of sulphates which I was able to find. Again, the specimen which I analyzed was taken from the north end of the lake; and it may be his was obtained from some other part, where springs abounding in sulphates empty into the lake. The small quantity of lime which I found, may have had a similar origin. I tested for iodine without success; but chlorine gave distinct indications of the presence of bromine.

The near approach to saturation of this water with common salt, excited the inquiry, which every geologist knows to be one of great interest, whether around the shores, or at the bottom of this lake, there may not be permanent deposits of that salt. Mr. Perkins has pursued the inquiries which I put to him on this subject in a very judicious and satisfactory manner. I give the result in his own words:

"The water of the lake rises every spring from three to five or six feet, during the annual freshets from rains, and the melting of snow on the surrounding mountains: and, as these cease, the lake gradually subsides to its summer level. In most places the land near the lake is flat, and but a few feet higher than the ordinary surface of the water. It is, therefore, extensively overflowed in the spring; and as the waters of the lake gradually subside, a very thin incrustation of salt is left on the land thus overflowed. This coat, however, is so thin, that it is difficult to collect it without a mixture of mud and sand."

"To procure salt clean and in large quantities, small ridges or intrenchments are made, eight or ten inches high, enclosing from one to four acres each, as the surface is more or less sloping. These ridges detain a sufficient depth of water, when the body of the lake retires, to deposit a layer of pure white salt (No. 225,) from one to three and a half inches thick, which crystallizes by the evaporation of a summer's sun. No other labor is required until the salt is to be collected. Over many miles of these flats, thus covered with a pure sheet of snow-white salt, I have rode to-day."

"The natives tell me that all the salt, which is not collected, (whether within or without the little ridges thrown up as entrenchments,) disappears during the rains and snows of the year."

"The natives also say, that for the last five or six years, from some cause unknown to them, the mean level of the waters of the lake has been several feet higher than formerly. And some say that before this rise, salt banks had gradually accumulated on the shore of the lake, which were permanent from year to year. All the natives whom I have consulted, do not agree on this subject."

Mr. Perkins adds in a postscript, that having consulted a bishop on these points, who lives on the shore of the lake, and whose testimony is unimpeachable, he has "no doubt but that such salt banks did exist on the shore, now covered with the increased waters of the lake. This bishop also stated of his own accord, that the surface of those salt banks was usually covered with a layer of sand, and that in penetrating into them you would pass through alternate layers of salt, and of sand or earth."

The bishop here referred to was Mar Yohannan, now in this country: and he still repeats the above statements, and adds another of importance. He says, that near his place of residence (Gavalan) there is a small pond, covering perhaps an acre, separated from the lake by a narrow and low sand-ridge, which has a permanent deposit of salt upon its bottom. Dr. Daubeny states this to be the case with lake Elton, and several other lakes in the vicinity of the Caspian Sea.

Upon the whole, the question, as to the permanent deposits of salt in lake Oroomiah, demands still further examination, although I doubt not that many respectable and honest natives can be found who live on its shores, and who believe that formerly such deposits were permanently formed.

The same may be said of another tradition, which prevails extensively among the inhabitants on the shores of this lake, and is even entered upon the public records of some of the villages, especially around its northern extremity. It is stated, that, sixteen or eighteen years ago, the waters of the lake suddenly disappeared, and left the bottom bare for a great distance, and that some young men, who followed the retiring waters, came at length to a great chasm. The waters, it is said, soon rose again to their accustomed level. Now this is not an impossible phenomenon, in a region so subject to earthquakes. But the difficulty is, that many natives seem to know nothing about it, among whom is Mar Yohannan. It is merely possible, but perhaps not probable, that such an occurrence might have happened at one end of the lake, without producing very marked effects at the other end.

Whence comes the extreme saltness of this lake? A few facts will, I think, give a satisfactory reply to this question. In the first place, the country to the east and north of the lake contains some of the most remarkable deposits of rock salt in the world. Large beds of it occur near Tabreez, in Red mountain; and from that mountain there comes down a stream, "several rods wide, of salt water; not so salt as the water of the lake, but too salt for comfortable use, though the natives do use it, which runs into the lake. Its name is *Âjee chai*, bitter, or brackish river." This mountain is about forty miles from the lake; but a salt plain extends from thence to the lake. Another bed of rock salt at Khoy, is only eight or ten miles from the north end of the lake. Here, then, we have an abundant source of the common salt in its waters. Its other ingredients may be derived from the remarkable mineral springs in its vicinity.

"At one locality," says Mr. Perkins, "about twenty miles south of Tabreez, and the same distance from the lake, near the village of Leewan, three springs issue within the space of eight yards of one another, and every one strikingly different in the quality of its waters from the others. One is hot, a second is acid, and a third is sulphureous, and highly fetid. And a few rods from these springs, on the opposite side of a stream, is a fourth, whose waters are impregnated with iron."

On the eastern shore of the lake, and quite near it, are the remarkable springs that deposit the famous calcareous alabaster, called Tabreez marble, which I shall notice more particularly further on. On the southeast shore of the lake, is another spring, which evolves carbonic acid, and deposits marble to some extent. On the west side of the lake, is a sulphur spring, about fifteen miles north of the city of Oroomiah. About thirty-five miles north of that place, on the north side of the mountain, between the district of Salmas and Oroomiah, is a hot sulphur spring, greatly resorted to by the natives, and depositing marble. It is four or five miles from the lake, is called *Issee Soo*, that is, *hot water;* and the present Prince Governor is now fitting up an establishment there for warm baths. Another salt and hot spring exists near Khoy. Surely, in springs so numerous, which must nearly all flow into the lake, we have a prolific source of the less abundant ingredients of that lake, although it is true that these springs have not been analyzed. But we know that they are carbonated and sulphureted springs, and probably they contain ingredients similar to springs of the same general character in other parts of the world.

I would here remark, that, in the facts above stated, we see the probable origin of the saltness of many of the lakes of Central Asia. The whole of that vast region appears to have been more or less subject to volcanic action; and as one of the results, a vast amount of chloride of sodium and other salts, has been produced. Oroomiah is thus rendered too salt for any sort of animals to live in its waters: though, from the fact that the flamingo is very commonly found wading along its shores, I strongly suspect that some sort of worms is found in the mud beneath the waters. But the Caspian is far less salt, and furnishes fine fish in abundance. The same is true of lake Van, which lies west of Oroomiah, and is of about the same size. In lake Elton, and some others in Asiatic Russia, already mentioned, the principal ingredient is chloride of magnesium, to which circumstance Prof. Daubeny attributes the precipitation of rock salt upon their bottom.

I have received no specimens from the vicinity of the Caspian Sea, except No. 552, from its shores. This sand is chiefly magnetic iron ore: but it contains also, manganese, and grains of olivine. This last mineral shows that the region around must contain volcanic rocks.

I ought to state, that the water from lake Oroomiah, whose analysis has been given above, was obtained about the twentieth of September, from the north end of the lake. A specimen recently brought by Mr. Perkins, which was procured near the city of Oroomiah on the first of July, that is, when the lake must have been much higher than in September, has a specific gravity of 1114, considerably less than that of the former, indicating the presence of a less quantity of salt; which is what we should expect.

I shall now give a more detailed account of the geology of the country around Oroomiah, so far as I am able to do it, from the specimens and descriptions furnished by Mr. Perkins.

"The plain of Oroomiah," says Mr. Perkins, "is about forty miles in length, as it lies upon the lake, and it extends back to the Koordish mountains, a high range of which, sweeping around in a semicircular direction, its two extremities reaching the water's edge, encloses the plain like a vast amphitheatre. This plain, at its widest point, where it swells a few miles into the lake, as well as retreats back into the curve of the mountain range, is about twenty miles broad. Its *appearance* from the heights back of it, is that of a perfect level: so much so, that the beholder can hardly resist the idea that it is a bed of tide waters, which is just laid bare by their ebb, and is soon to be enveloped by a returning flow. In fact, however, there is a considerable descent from the mountain side of the plain to the lake: and the three considerable rivers, (each from one hundred to two hundred feet wide,) which roll down through rugged ravines in the mountain range, flow across the plain and pour themselves into the lake with rapid currents. I am not aware, that the lake ever does overflow more than a mile or two of the shore, even in the spring, and it has no tides."

"The plain of Oroomiah, in reality as well as in appearance, is extremely fertile. With the adjacent declivities of the mountains, comprising an area of about six hundred square miles, it sustains three hundred and fifty villages; almost every inch of the soil being under cultivation. Its almost entire and frequent irrigation, by means of small canals from the rivers, and the immense annual growth and decay of vegetation, are the secret of the unhealthiness of our climate."

That the causes here suggested by Mr. Perkins are among the sources whence disease originates on the plain of Oroomiah, I do not doubt; but I must be allowed to suggest, as other causes, the great quantity of sulphureted hydrogen generated by the lake, and of carbonic acid from the mineral springs in the vicinity. These two gases, I believe, are now generally regarded as among the most pernicious of miasms. Not improbably these gases are produced from the soil of that region, especially in low and damp places, as well as from the lake. Alkalies or lime-water, could they be employed, would absorb the carbonic acid; and nitric acid, or burning sulphur, the sulphureted hydrogen.

"The soil on the plain of Oroomiah," continues Mr. Perkins, "is a dark-colored alluvium. Having occasion a few years ago to superintend the digging of a well on our mission premises, I observed that this alluvium was two and a half feet thick; and I have observed the same elsewhere, as I have seen the natives digging canals for irrigation on different parts of the plain. In digging our well, we were obliged to go down about sixty feet for water. After passing through the alluvial stratum, we came to drift, consisting of coarse sand, gravel, and pebbles; the larger stones being of the size of the fist, and many more than twice as large; the whole much resembling the soil on the hill in front of your college (at Amherst) where we labored to form terraces when I was a student there. This drift we found to be eighteen feet thick. We next came upon hard yellow clay, which continued until we reached water; that is, about forty feet. Such I am informed is the usual order and thickness of these deposits."

"You will be surprised to learn, that our well-diggers penetrated the earth to this depth without the least protection of anything like a curb. They dug the well about three feet in diameter, and enlarged it a little as they descended. They dig in this way at all seasons of the year for the moderate sum of eight to twelve cents per yard."

In conversation with Mr. Perkins, he informs me, that the soil of this remarkable plain is quite similar to that of the prairies of our Western States; and one of his fellow missionaries, who is familiar with our prairies, has remarked, that he had never seen a richer soil, except in one or two places, than that of Oroomiah. Whether the deposits of gravel and clay below the alluvium is to be regarded as connected with drift, or tertiary strata, we have scarcely materials enough to decide.

I incline to the belief, that the fertility of this plain depends in a great measure upon the common salt, which probably exists in the soil of that region generally. It is so much diluted by irrigation, as to prove an admirable manure. A salt desert is an image of perfect sterility; but let fresh water enough be brought over it, and I think we have facts to warrant us in saying, that the desert will be changed into a Paradise of flowers and fruits.

As we come to the hills surrounding the plain of Oroomiah, limestone is for a time the predominant rock. This is evidently of secondary or tertiary character. Some of it, as Nos. 210, 213, and 214, is chalky, and resembles the limestones of mount Lebanon. But Prof. Bailey could not find in it any remains of Foraminifera. A few of these varieties I analyzed.

No. 214 is from a mountain fifteen miles northwest of the city of Oroomiah. It is used for purposes of building, and by the Nestorians for gravestones, in large blocks. The specimen analyzed was broken from the monument over Mrs. Dr. Grant, the wife of an American missionary. In one hundred parts I found,

Earthy residuum,	0.33
Carbonate of magnesia,	0.83
Carbonate of lime,	98.84
	100.00

No. 210 is another variety from the same mountain, and is used in Persia for hydraulic cement. The native name for this rock is *Ahak*. In one hundred parts I found,

Earthy residuum,	0.66
Carbonate of magnesia,	0.55
Carbonate of lime,	98.79
	100.00

If this is a fair specimen of this limestone, and if our notions respecting hydraulic cement are correct, I hardly know how to explain the fact, that this rock should produce such cement. But I believe the analysis to be essentially correct, and I must leave others to explain the difficulty.

A very common and impure limestone is Nos. 200 and 201. It occurs on the mountain west of the plain, in layers from two to four inches thick, and is used extensively for paving, building, and gravestones. I should suppose this might make a better hydraulic cement than No. 210.

Connected, probably, with the limestones above described, gypsum is abundant. It occurs in an insulated hill, fifteen hundred feet high, on the plain of Oroomiah, whose central part is composed of primary rocks. No. 212 is an example of this gypsum. It occurs, also, in the hills on the west side of the plain, and is extensively used in that country as a substitute for limestone, in forming plaster for walls. The precise process for converting it into mortar, and its comparative durability, I have not been able to learn, as the natives seem to confound this with limestone.

I suspect No. 211 to be gypsum, mixed with a few per cent. of carbonate of lime. Certainly it exhibits a lively effervescence with an acid, but most of it remains undissolved. It is softer than common gypsum.

In passing into the mountains west of the plain, extensive deposits of coarse conglomerate are met with, but of their nature I cannot judge without a specimen.

Finally, the prevailing rock in those mountains is granitic gneiss. No. 198 is an example, and has the appearance of granite; but Mr. Perkins says, it is in strata, which have a southeasterly dip from twenty to thirty degrees. I doubt not, therefore, that the Koordish mountains are composed of primary rocks; and if we can place dependence upon the maps of that country, these mountains extend northerly nearly to Ararat; and southerly, far towards the Persian Gulf. They seem to form the great watershed between the streams that flow westward into the Tigris and Euphrates, and eastward into the Caspian Sea. I doubt not that along that ridge will be found very extensive deposits of crystalline rocks.

Some of the small islands in the lake are said to be composed of quartz rock. No. 199 is from near Tabreez, and is used with the incinerated seaweed, No. 226, growing on the borders of the lake, for making glass. It is said to be abundant in various parts of Persia. Some of the islands in the lake are composed of limestone. Petrifactions occur on some of the islands, and though I have no specimen, Mr. Perkins is confident, that some of them are vegetable and others animal.

Mr. Perkins was informed by the present Prince Governor of the province of Azerbijan, whose name is Malek Kasem Meerza, that on a hunting excursion in the mountains west of Oroomiah, he discovered a magnificent cataract, about twenty miles from the lake, where the water tumbles wildly from cliff to cliff from the height of nearly four hundred feet, showing the rainbow frequently upon its spray. This Prince shows a strong disposition to introduce European improvements, and lately set men digging for coal in the mountains, on no other ground, than that coal frequently occurs in the vicinity of iron; and he knows that the latter is found in those mountains.

I have alluded to the great quantities of fossil rock salt found in the region to the east and north of Oroomiah lake. The plain between the lake and Tabreez is called a salt plain, from the presence of this substance. Near Tabreez there rises a naked mountain, which, from its color, is called Red Mountain. Nos. 203 to 208, are specimens of the rocks found there; and one cannot look at them without perceiving that they bear a strong resemblance to varieties of the new red sandstone of Europe and America. Nos. 203, 204, and 207, however, appear as if they had been exposed to a strong heat, which has nearly expelled the red color. No. 206 is a conglomerate. In this rock occurs an extensive deposit of rock salt, the purest that I have ever met. No. 209 is an example, as limpid as rock crystal. And on examining it chemically, I cannot detect a trace of a sulphate, or of lime, or of magnesia, or of iodine, or bromine; most of which are usually present in fossil salt. It is the first specimen of fossil salt which I have ever found perfectly free from foreign ingredients. In one of the crystals there was a fluid, as shown by a moving bubble.

So far as lithological characters can go, the probability is strong, that this formation is the new red sandstone. I have another fact in favor of the same view. On the plain of Khoy, eight or ten miles northwest of the lake, is another extensive deposit of salt, connected with a similar red rock, with limestone, (No. 453,) and with gypsum, (No. 455.) The bed of salt is ten feet thick, and is quarried, although not as pure as that at Tabreez. Is not the probability very strong, that the deposit containing these minerals is the new red sandstone? Examining the salt from Khoy chemically, I find in it sulphuric acid, lime, and magnesia, in about the usual quantity, but neither bromine nor iodine.

As we go northerly from this lake, we shall find, according to the researches of our countrymen, Messrs. Dwight and Smith, another bed of salt, a little north of Nakchevan, east of the Aras, in Georgia: a second bed, a little northeast of that place; a third, west of Erivan; and, indeed, all along the Aras, salt is abundant a little beneath the surface, as far as Kars, and perhaps further. If now we look southerly from Tabreez, we are met upon the maps with the great salt desert in the central parts of Persia, extending almost to its southern borders; and there can be little doubt but this is a continuation southward, of the saliferous deposit in the north of Persia. If so, it must be nearly one thousand miles long, and of great breadth. Again, it can hardly be doubted, that this formation reaches the Caspian Sea, since that is salt; and also other inland lakes in Tartary; so that probably the formation extends as far northeasterly from Oroomiah, as it does northerly or southerly. We catch, indeed, but glimpses of the extent of this formation; but we see enough to make it probable, there is not such another salt deposit on the globe; enough to show us what an interesting task lies before some future geologist, in tracing out the geology of these wide regions.

I have alluded to the deposition of marble, or alabaster, by certain springs in the vicinity of lake Oroomiah. What is called the Tabreez marble has been repeatedly described by travellers; but I doubt whether very definite geological ideas have yet been entertained respecting the mode of its formation. With the exception, perhaps, of a deposit of travertin around Rome in Italy, resembling statuary marble, I am not aware of any case besides those around Oroomiah, in which the most beautiful marble is produced by springs. The Tabreez marble, of which Nos. 220 and 221 are examples, is usually of a yellowish or light blue color, perfectly compact, and so translucent, that it is used in thin slices for the windows of baths and other places, like the *phengites* of the ancients. It occurs not far from Maraga, on the east side of lake Oroomiah, and about half a mile distant from it. Immense quantities of this alabaster (for it is the true calcareous alabaster) have been dug and carried away. The common opinion is, that the springs now deposit it; but one or two facts have led me to suspect that this may not be the case. Above the marble there lies a deposit, several feet thick, of common tufa, or travertin. Now my suspicion is, that this tufa is all the deposit which has been formed since the springs assumed their present state; and that the alabaster was deposited when their temperature was higher, and when perhaps they were beneath deep waters. However, this opinion is little better than conjecture. That this substance often has a concretionary structure, appears from No. 220.*

From the resemblance of the calcareous alabaster from the Pasha's palace in Cairo (No. 385), as already described, I was led to anticipate a similar composition of that from Maraga. And, indeed, it is perfectly soluble in acid. But I found the ingredients in one hundred parts to be,

Proto-carbonate of iron, . . .	2.93
Carbonate of magnesia, . . .	1.33
Carbonate of lime, ...	95.74
	100.00

A spring similar to that which produces the marble above analyzed, exists on the southeast shore of the lake; but whether it has deposited much marble I cannot say. Another exists on the promontory near Salmas, as you begin to ascend the northern side of the mountain. No. 470 is an example, and shows the concretionary structure exhibited in that from Maraga. By analysis, I find that one hundred parts of this specimen contain,

Proto-carbonate of iron, . . .	1.95
Carbonate of magnesia, . . .	1.06
Carbonate of lime, ...	96.99
	100.00

* MORIER gives a detailed account in his travels, of the manner in which this alabaster is deposited by the water of these springs; but his description appears to me misty and unsatisfactory. Neither he, nor any other writer whom I have seen, explains how it is, that the marble is covered by several feet of porous or common travertin.

Will the facts above stated throw any light upon the general subject of the origin of rock salt? That this substance in Asia, as in other parts of the world, is usually connected with rocks of rather recent igneous origin, seems fully established. But do not the facts respecting the exceedingly salt lakes of Oroomiah, Elton, and others, render it extremely probable that beds of salt, alternating with beds of earth, may have been formed,—indeed, are now forming? So that, although originally of volcanic origin, subsequent alluvial agency may redeposit it. And will not this double origin of the substance best accord with facts?

I will refer in this place to an interesting specimen of marble, obtained by Rev. Mr. Merrick, in the ruins of Persepolis. It is a dark gray, argillaceous, bituminous limestone, with casts of univalve shells. (No. 202.) In dissolving this stone in hydrochloric acid, it gave off a strong bituminous odor; but the quantity of bitumen in it is not very large. I found in one hundred parts,

Earthy residuum, ...	2.33
Carbonate of magnesia, . . .	2.21
Carbonate of lime, ...	95.46
	100.00

It would be strange, if such limestone would not form a good hydraulic cement. But the locality of the quarry from whence it was taken, I do not know. It is not a rock, however, that would be carried a great distance, because not handsome; and, therefore, we should expect to find the quarry not far from Persepolis.

No. 216 is an exceedingly rich ore of copper, from a mine about sixty miles northeast of Tabreez; and of course not far from Georgia. It is mainly native copper, incrusted with the green and blue carbonates, and mixed with the red oxide. The native copper exists in some of the cavities in crystals. This mine is extensively worked by the Persians, and is said to be very rich. A large number of cannon have been cast from it for the Persian government.

Phenomena of Drift in Western Asia.

With a few statements respecting the phenomena of drift in Western Asia, I shall close this paper.

This is the most difficult of all geological subjects, on which to obtain information, in countries whose geology has not been thoroughly explored. The most intelligent traveller may pass through regions prolific in marks of what I call glacio-aqueous agency, without noticing them, unless he has been previously familiar with the phenomena. Still I think our missionaries have furnished a few facts, making it probable that eastern countries are not destitute of such phenomena.

To begin with Armenia. Before Mr. Perkins left this country, he accompanied me to a striking example of what have been of late called moraines, produced not by glaciers alone, but by ice crowded along the surface in any mode, whether by expansion, water, or gravity. I requested him to inform me, whether any similar phenomena came under his notice in the east. Soon after his arrival there, he says, that on the vast plain to the north of Ararat, and considerably distant, "we passed many sections of drift, much like the one we visited back of Amherst." On his return recently to this country, he thus writes from Trebizond, under date of August 13th, 1841.

"Just back of the city of Trebizond, is a mountain, about six hundred feet high, which runs from the seashore around the city, and which is called by the natives, *Bos Topa* or *Azure Hill.* About half way up this mountain, Mr. Johnston (American missionary there) pointed out to me some striking geological features. Directly on the declivity is a section of strongly marked drift, consisting of coarse gravel and sand. A small ravine having conducted the water down to the top of one of these hills, it has been gullied to the depth of twenty feet, which reveals the sand and pebbles to that depth. Further along, on the side of the mountain, and at just the same height, we observed, where a road had been excavated, a deposit of the same drift in the crevices of the rocks."

"I have often observed, in different parts of Western Asia, particularly in Persia, hills of drift; but none so regularly conical, or rather *inverted-punch-bowl-shaped,* as those on the declivity of this mountain. And I have very seldom observed the *diluvial punch-bowl hollows*, which so abundantly occur in America. Mr. Johnston, however, informs me, that he observed very striking examples of such hollows in ancient Cilicia, on the river Halys, near the present town of Sivas. In the same region, too, he observed a section of alluvium and drift, (which was laid open by a rapid stream, issuing apparently from the ground at the head of the section,) and which was four hundred feet high; the whole presenting very striking geological features."

It is difficult not to recognize in the preceding accounts, what are called ancient moraines, by Agassiz, Buckland, and others. Those at Trebizond have probably been brought into a conical shape, and are insulated by alluvial agency, subsequent to their original production. Some insulated cones of this description occur on the plains of Oroomiah. There are not less than twelve or thirteen of them, and some of them, according to Mr. Perkins, cover an acre and a half of ground, and are from seventy-five to one hundred feet high. In that region they are universally regarded as artificial, and the work of the ancient fire-worshippers. For on digging into them, walls of stone are found laid up to their centres, and much of the soil seems to be little else than ashes.

It may appear presumptuous in me to doubt the artificial origin of these mounds. But in the first place, similar mounds occur in various parts of the northern hemisphere, and are almost every where regarded as artificial; whereas geologists are discovering from time to time, that many of them are the result of aqueous agency, either during the drift period, or the alluvial. In the second place, if these mounds existed before man, it is not strange that man has chosen them as a place on which to erect forts, perform religious rites, and to deposit the dead. It would be reasonable to expect, that the fire-worshippers would choose them as the spot best fitted for keeping up the perpetual fire. In the third place, Mr. Perkins informs me, that some of them at least, where he saw them dug into, exhibited a stratified arrangement of their materials. This fact appears to me quite decisive in favor of their aqueous origin; for what human skill can arrange fine and loose materials in the manner that is done by water? Finally, the work of erecting them is too great for a people in the rude stages of society. I cannot, therefore, but strongly suspect that they may be the remnants of a formation which once spread over the whole plain; the most of which has been swept away. I doubt, however, whether they are connected with drift; since the materials composing them are fine, and not gravel, and are, moreover, sorted or stratified.

Robinson and Smith have described a large number of tumuli of gravel on the west side of the Jordan, near Jericho. As some of them were covered with the remains of buildings, it was very natural to suspect them to be artificial. But the great number scattered over the plain, rendered the supposition improbable. Dr. Robinson was so kind recently, as to accompany me to a region of tortuous and round-topped moraines in Amherst, that I might satisfy myself whether their materials are similar to those around Jericho. He declared that there was no difference, except that those in Palestine are insulated cones, and those in Amherst irregular and tortuous. The insulated ones, however, are very common in New England. I cannot, therefore, but strongly suspect, that those in Palestine were produced by glacio-aqueous agency.

In passing through the Wady el Arabah, south of the Dead Sea, Dr. Robinson describes some examples of bowlders and of gravel and sand-hills, of such a character and extent, as to lead one strongly to suspect them to be the result of the same agency. But further observations will be necessary to settle the question.

The most decisive example of glacio-aqueous agency which I have met with as occurring in Western Asia, is given in the Journal of the American missionary, Mr. Beadle, in Northern Syria,— as related in the Missionary Herald. In travelling northerly along the coast from Beyroot, sixty or seventy miles, he "reached a volcanic region with a remarkable locality of greenstone. The pebbles from this locality are scattered the whole distance to Beyroot. At that place they are quite small, but gradually increase in size as you advance to the north, and terminate entirely in this locality." If such a case as this had been found in Northern Europe, or New England, no one would have doubted at all that it was a genuine example of the dispersion of bowlders during the period of the deposition of drift. Some might, indeed, suppose that these bowlders and gravel were carried southerly by the waters of the Mediterranean, when their whole track was beneath the waves. But such a dispersion could not have taken place without ice; and to introduce this, carries us back to the drift period, which is admitting all that I contend for. Beyroot lies in north latitude, thirty-four degrees, and this is certainly further south than any glacio-aqueous agency has been hitherto detected.

But I must close; and I cannot do it in a better manner, than by quoting a few remarks from a private letter from Mr. Perkins, in 1839, on the importance of a knowledge of geology to the missionary. "Did not my missionary work," says he, "press upon me so constantly, and with such mountain weight, I should feel strongly tempted to study geology, (of which I know very little,) so wonderfully interesting, in a geological point of view, does the face of Persia appear to me. Indeed, I often feel that this interesting and important science has peculiar claims on American missionaries. Visiting, as they do, all portions of the world, they enjoy opportunities of contributing to it, with almost no sacrifice of time or effort, which are possessed by no other class of American citizens. I know not that I can better atone for my own deficiency in this respect, than by requesting you, in my behalf, to urge upon the missionary students in college, the high importance of their obtaining a good practical knowledge of geology and mineralogy, while attending your lectures, as they would enhance their usefulness in future life. It is the combined light of ALL TRUTH, *scientific* as well as *religious*, which is to render so perfect and glorious the splendors of millennial day."

APPENDIX. — A part of my collection of specimens from Asia, consists, as already intimated, of rocks and minerals, sent from Ahmednuggur, in India, more than one hundred miles east of Bombay, by Rev. E. Burgess. They were obtained in the vicinity of that place; and show that trap rocks make up most of its geology.

But they show, also, that these rocks are probably a rich repository of zeolitic and chalcedonic minerals; and, therefore, I append a catalogue, although it has long been known that that part of India afforded such specimens, and it may be that this particular locality has been described.

Nos. 556 to 559. Compact basalt, or greenstone: the common rock.

Nos. 560 to 565. Tufa, or toadstone: the cavities filled by green earth, heulandite, and calcareous spar.

Nos. 566, 567. Amygdaloid: cavities filled with beautiful green earth (?) and natrolite, or mesotype, in silken tufts.

Nos. 568 to 573. Amygdaloid: the cylindrical cavities filled with chalcedony, coated by green earth, calcareous spar, quartz, and zeolitic minerals.

Nos. 574 to 579. Trap tufa, with nodules of calcareous spar and zeolites; except No. 577, which is brick-red amygdaloid, with druses of calcareous spar.

No. 581. Stalactical chalcedony, with zeolites.

No. 582. Chalcedony, having the form and appearance of a vegetable stem, an inch and a half in diameter.

Nos. 583 to 587. Geodes of crystallized quartz. Crystals hexahedrous, with hexahedral summits.

No. 589. Quartz geode: crystals six-sided prisms, with trihedral summits.

Nos. 590 to 592. Stalactical quartz: the cylinders from an inch and a half to three inches in diameter, and often six inches long: sometimes compact, with a mamillary or semi-crystalline surface: sometimes the crystals have trihedral summits.

Nos. 594 to 600. Rhomboidal crystals of calcareous or Iceland spar: generally transparent, sometimes smoky.

No. 605. Soft compact limestone: a common rock.

No. 606. Thomsonite: in radiated masses, four inches long.

No. 607. Stilbite, in radiating masses.

Nos. 608, 609. Crystallized Apophyllite, with quartz. The crystals show two four-sided pyramids, slightly truncated at the summit, and at their bases: but the faces of the original primary right square prism, are almost obliterated.

No. 613. Brain Coral (Meandrina), from the island of Zanzibar, broken from a rock three hundred feet above the ocean.

Remarks upon Casts of Mud Furrows, Wave Lines, and other Markings upon Rocks of the New York System. By James Hall, *of Albany*, N. Y.

The surface of strata in all the shaly or intermingled shaly and sandy deposits, from the oldest of the kind up to the coal, and even in the new red sandstone, present us with many peculiar markings, which, for the most part, can be referred to no known organic forms, and from analogy are considered as due to the influence of physical causes in operation at the time of the deposition of the strata. Among these have been recognized the ripple-mark, and the impression of rain-drops; the one indicating shallow water or a dry beach, and the other a condition of soft mud, which could be impressed by the force of rain-drops. The great depth of deposits above these, prove their subsequent subsidence, allowing other strata, often marked in the same manner, through many feet in thickness, to be deposited upon them.

The most remarkable rock impressions are those of the feet of reptiles and birds, which are likewise often found in connection with those alluded to.

Besides the markings enumerated, are numerous others, which have been referred to Fucoides, or marine vegetation of some kind; but these are so dissimilar, that they could have been produced only by forms belonging to very different families of plants, if indeed many of them are organic at all. In regard to many of these forms, it is quite evident that they are due to inorganic or dynamic causes, and not to the influence of organization. The situation, position, association, and all other circumstances, prove them to have had this origin. Certain of these are always found upon the under side of hard layers, and always at the junction with a softer one below, a position which corresponds with that of many of the fucoides or marine vegetables. These are frequently attached to the lower side of the stratum, as if growing upon a soft bottom, and becoming imbedded in the next deposition. There are also other appearances, which seem to be due to accretionary action, by which irregular markings upon the surface of strata have been produced. Aside from these, however, are forms somewhat resembling them, which bear no marks of accretionary force; and if due to that action, it must have operated very differently from the same force in other well-defined instances. Those to which I now allude, present all the appearance of fluid mud; of such a tenacity that the current was broken, presenting several small streams, much resembling flowing cinder from an iron furnace. The surface often presents a series of interrupted semicylindrical ridges or corrugations, one behind the other, which at first view strongly impress one with the belief that they are due to some fluid body of a considerable degree of consistence.

This peculiar appearance sometimes covers only a small portion of a slab of rock, where it thins towards one side, while in others the whole surface is covered, giving the aspect of a body cast in mud, which had been irregularly scooped out by the action of shallow currents. Similar appearances are often seen in flat beaches composed of mud and sand, over which a stream of water spreads during the ebb tide. The whole surface, in such cases, is scooped into little circular hollows, communicating with one another by narrow depressions. If a deposition of sandy mud could be made upon such a surface after it had become sufficiently dry, its lower surface would present all the appearances here described as seen in many of the higher strata of New York. That such a condition may have existed, is demonstrated by other phenomena, which are proved to have happened at intervals, when the matter already deposited was near, or above the surface.

The sketch, Pl. XVII, fig. 1, represents one of these surfaces near the thinning edge of a sandy stratum,* and is one of the common appearances in the Portage group. This form, under many modifications, prevails extensively not only in the higher groups of New York, but in specimens which I have recently seen from the Connecticut River Valley, and which, Prof. Hitchcock in-

* For an analogous recent production, see Geol. Report of Massachusetts, p. 348, fig. 59.

forms me, are of frequent occurrence in the new red sandstone series.

In the strata exhibiting these peculiar appearances, I have never observed the ripple-mark, although it frequently occurs but a few feet below or above, and always within a short distance, indicating that the markings, whatever may have been their origin, were produced in shallow water, at least.

Associated with these markings is another kind, which thus far I have been unable to refer to any known cause. They consist of a series of minute parallel ridges, or extremely low terraces, not more than an eighth of an inch broad, and one quarter of this height, in truth, barely perceptible, as having this form. But from the fact of having noticed them in the Portage group of New York, and seeing the same in the collection made by Prof. Hitchcock from the new red sandstone, it seems that they were due to some cause operating in the same manner at these remote periods, and in both cases they are in conjunction with those previously described.

Casts of Mud Furrows, grooved and striated Surfaces.

The kind of markings most numerous in these rocks are the straight ridges of various lengths, which are usually referred to fucoides as their origin. There are, however, many attendant circumstances, which prove them to be the productions of a different cause. The fucoides, with no determinate general direction, are either straight or curved; they are usually short, and rarely exceed two or three feet in length. The markings in question have all a uniform direction or nearly so, and can often be traced many feet; they are round or angular, the two kinds sometimes appearing together upon the same slab. They are always upon the under surfaces of strata, being attached to a hard layer which rests upon a soft one.

In dimensions, they vary from the diameter of half a foot to that of half an inch, and we find innumerable instances where they present all the appearances of casts of striæ or shallow grooves, very much as if an impression were taken from the grooved and striated surfaces of glacial furrowed rocks.

Pl. XVII, fig. 2, represents a specimen of the kind last described, where the surface presents slight ridges, as if the deposition had been made upon a surface previously hardened to a considerable degree, and which was grooved and furrowed like the surfaces of our present rocks. It is not usual to find grooves in two directions, as in this instance.

These appearances cannot be explained by supposing a motion in the mass, by which one part was made to slide over another, for we find them at about the same position in the rock, at intervals, over a distance of twenty or thirty miles, and it must be remembered that the strata are almost horizontal, and quite undisturbed. The different degrees of hardness in the two masses in contact would prevent any such conclusion, for the lower one is too soft to impress the upper, which is the one presenting the marks. The aspect of the surface is likewise different from a grooved or striated one, the lines being in relief, lying in corresponding depressions in the shaly stratum below.

Those appearances to which I have strictly applied the term, casts of mud furrows, are straight or sometimes slightly deflected longitudinal ridges, which are found upon the lower surfaces of strata. They appear to have been originally furrows made in the mass beneath, while in a partially indurated condition, and filled with the subsequent deposit, which has preserved their form and inequalities. Some of these are deep and narrow, as if made by a heavy body dragged over the surface; others appear due to a jagged or rough-pointed surface, impressing the stone or mud, and the cast presents all these appearances.

These ridges have all a uniform direction, varying but little from northwest and southeast. This uniformity occurs in localities widely separated from each other, indicating some cause which has operated over a large area, and in a uniform manner. Oftentimes several of these ridges are seen upon the surface of a single slab, and, except in rare cases, are always parallel to each other. In a few instances I have seen several of these parallel ridges crossed by a single one at an angle of about thirty degrees, its course as regular and well defined as the others. In no case have I observed them upon the upper surface of the strata.

In a few instances I have found these ridges or casts covered with shells, which apparently were floated over the even surface, and lodged in the furrow previously made. These have adhered to the next deposition, and are now found attached to the lower surface of the same.

Pl. XVII, fig. 3, represents the section of a thin slab of this sandstone with one of these semicylindrical ridges upon its under side. On the most convex part of the ridge, at *a*, the surface is covered with small fossil shells, while the plane surfaces on either side *b b*, are entirely free from them. This would seem to indicate that the shells were floated into the furrow or depression previously existing, and there remained, the current not having power to remove them, while it swept all from the even surface to similar situations.

Such are, briefly, a few of the facts attendant upon these ridges or casts of mud furrows. I have not been able to trace any thing like organization in any of them, and their variable character, as respects form, size, and general symmetry, are strong arguments against their having had such an origin. While, on the other hand, their uniform direction, and parallelism, so essentially different from the fucoides, indicate a force that operated in one general direction, varying sometimes to the amount of a few degrees. These ridges are sometimes much larger at one end than at the other, as if the furrow which they filled was made by a heavy body grounding, and then being gradually raised and moved more lightly over the surface, and finally the impression running out entirely. In some of these casts the peculiar fractured character is apparent, as if the force making the groove had a tremulous motion. The same is seen, in some degree, in the more recent diluvial or glacial scratches. These appearances have been traced from New York as far westward as Indiana, and all possessing the general characters here described. At the same time, fucoides frequently accompany the same strata, but these can usually be distinguished from the casts.

The numerous fragments of fossils and drifted shells which accompany the same strata in many instances, sometimes forming layers of themselves, together with other circumstances, indicate a shallow ocean or a littoral position.

At some future time I hope to be able to offer to the Association the results of more extended observations. In the mean time, the object has been to call attention to the facts, in the hope that the observations of others would be directed to the same subject, and by this means new light would be thrown upon the matter, or some more satisfactory explanation given of the cause of the phenomena.

Wave Lines.

There are still another kind of markings, which are presented as minute ridges upon the surface of strata, scarcely raised above the uniform level, yet perfectly defined, pursuing no definite direction, but always more or less curved or undulating. These are not as common as the forms just described, and appear only for limited distances. The most decided and best characterized which I have seen, are in the Medina sandstone, and confined to strata forming but a small portion of this rock, appearing neither above nor below this position.

Plate XVII, fig. 4, copied from the Report of the Fourth Geological District of New York, will give an illustration. The surface, from which this is reduced, is about five feet long by three wide, being a slab quarried about one mile north of Lockport. The figure illustrates perfectly the manner in which these lines occur. From the inner side of each curve there is a slight elevation in passing outward, but which slopes gradually down to the surface beyond. I have called these markings *wave lines*, from their perfect similarity to the lines or ridges left upon sandy beaches by the retiring wave.

Any one, who has passed some time upon the bays of the ocean, bordered by almost level sandy beaches of many rods in width, will not fail to have noticed, that each retiring wave leaves behind it a small line or ridge of sand. It frequently happens, that from the ebbing tide or the lulling of the wind, each successive wave reaches less and less high up the beach; and consequently a succession of these lines is left, till the rising tide or wind brings back the water and obliterates them.

The same appearances are beautifully exhibited upon the sandy shores of our large lakes, when, towards evening, the wind dying away, leaves long beaches covered with these delicate lineations. It often happens, that during this process several successive lines are left, and then a wave larger than the rest advances and sweeps away the whole, forming a line still higher up the beach. But at the same time the wave may not reach as far laterally, and then we have the appearance of a single line in the centre, separating into several at the two extremities. This is readily conceived, if the same fact has not been observed, and it is illustrated in the wood cut.

The process by which the ridge or line is formed, seems to be this. The advancing wave, by its momentum, carries forward a small quantity of sand upon its crest; when the wave reaches its limit, the momentum being lost, and the sand being in advance, there is no force to carry it back with the retiring water, and it is thus left upon the beach marking the extreme verge of the wave. This seems to be the simple and rational explanation, where the wave is advancing directly upon the shore. When the direction of the wind is oblique to that of the shore, the wave sweeps onward, advancing upon and receding gradually from the shore; in such cases the deposition seems to take place from the centrifugal action of the wave throwing the sand beyond the limit of its power.

If from the sandy beaches of our lakes and from the sea-shore we go to the sandstone quarries, the analogy of these lines is too close to be mistaken. It leaves no doubt as to the cause. It seems as if the lake or sea beach had been converted into solid stone while yet washed by the waves, and we can almost fancy that the returning tide will obliterate them all. It is, indeed, remarkable, that these faint traces of waves should be preserved through successive layers, for many feet in thickness. How could these faint lines in the loose sand of a sea-beach have been preserved while other depositions were being made upon them? And how could the sea have retired, and again have covered the surface, leaving as it went these lines, and returning, apparently with a fresh deposit, which, on retiring again, was left marked by its retreating lines? It may not, indeed, be easy to answer satisfactorily in what manner this was done, but it seems very rational to suppose that this sandstone deposit was at that time a long, level, or nearly level sandy beach, like some upon our present sea-shore, and that the tide ebbed and flowed over this to a great distance. It may have been so nearly level, that a rise of a few feet perpendicular would cause the water to flow over many rods in breadth.

If the condition could have been that which would cause the hardening of this surface while the tide was out, the return of the wave with a fresh deposit would not obliterate the old lines, but preserve them, and in this way every fresh deposition would preserve the former lines, and in turn be marked by similar lines itself.

It is very evident, that the depositions of this period were very thin, as we find layers separated by divisional planes, and often some little foreign matter between each, which are less than one eighth of an inch thick. All these laminæ, however, are not marked by wave lines; some indicate a quiet and undisturbed condition of the water, as if the tide ebbed and flowed without wind, as was doubtless the case at times. We have thus conclusive proof of the state of this ancient ocean in regard to wind and tides, and that, like our present ocean and its bays, it was sometimes moved by winds, and at other times quiet and unruffled.

Difficult as it may be to conceive of a condition capable of preserving such minute traces of former operations as these wave lines, still we know that marks, equally liable to be erased, have been preserved through successive deposits, under what may be considered precisely similar circumstances, in great numbers, and over a great extent of country. These are the footsteps of Batrachian animals in Germany and England, and of birds in America, which are preserved through successive strata in the new red sandstone, with almost the same integrity as recent footsteps in clay, or the maker's name upon a burned brick.

The discovery of bones leaves no doubt of the origin of the footsteps in England and Germany. In the Connecticut River Valley, Prof. Hitchcock has discovered, extending through successive strata, the footsteps of birds; these, too, minute as many of them are, are still preserved in all their integrity; so much so, indeed, as to allow of specific distinctions being founded on these characters alone.

After such proofs as these, we cannot doubt the first; indeed, the one corroborates the other; and although in the wave lines we may never find other proof than that afforded by analogy, or comparison with recent effects of the same kind, yet the resemblance is so impressive, that we cannot doubt. In the case of the foot-prints, we have both analogy, and in some cases, already, demonstrative proof. In the wave lines, the analogy is equally strong as in the foot-prints, before bones had been found, which indicate an animal capable of making such impressions.

Believing that we shall be willing to admit this as a new fact in physical geology, the age of the rocks in which these marks occur, enables us to extend back, for a long period, our ideas of the time when nature operated as she now does, by winds and waves, upon the present shores; and it follows, too, that the limits of the ancient ocean did not every where extend to the great primary chain of mountains at the East.

During the last summer I have had the pleasure of reëxamining these markings upon the rocks, as well as witnessing again the effects of waves upon the sandy shores of our lakes, in company with our distinguished visiter, Mr. Lyell, and I am happy to say, that his opinion confirms what I have here stated, and encourages me to offer the facts to the notice of geologists, hoping that they may be found of interest and importance.

From the course of these wave lines we learn, that the wind was generally in the direction from the north-northwest, or varying from northwest to north, proving that the surface was higher to the southeast, for a wave line cannot be made upon a perfectly horizontal surface, although a ripple-mark may. The dip of the strata is now southward, the surface inclining in an opposite direction from what it did at the period of deposition. In the numerous specimens and surfaces which I have examined at the quarries, the direction of the wind appears to have been uniform during successive depositions. This constant direction of the wind from one quarter would indicate that there were no extensive highlands in the vicinity, as these would have more or less influenced the direction.

Throughout all the strata thus marked, there are no ripple-marks; though, in strata above and below this point, they are common, and within ten feet of the strata marked by wave lines I have seen rippled surfaces.

Notwithstanding, it is evident that this portion of the strata remained above water, or so that it was washed by the retiring tide for some length of time; yet it is equally evident, that it did not become permanently dry land. It appears more like a sand-bar, or elevated portion of the ocean bed, which might have been dry a part of the time. It should be mentioned at the same time, that this portion of the rock, thus marked, is a gray quartzose sandstone, while both below and above, the mass is a red shaly sandstone. The gray color does not appear due to any subsequent action, but to have been that of the deposit. The great horizontal extent of the mass forbids the idea, that it was due to a sudden or local phenomenon, for the numerous thin laminæ, of which it is composed, indicate a considerable period of time. It is further remarkable, that during this period there was an entire cessation of the shaly deposit, which occurs just above and below, and the coloring matter also, for the most part, ceased during the same time. (N. York Geol. Report, 4th Dist., Art. *Medina Sandstone.*)

In view of the facts first stated, if they are admitted to be substantiated, we must conclude, that denuding agencies have operated at remote periods of the earth's history, not only between great geological eras, but during the deposition of products, which form one system. The absence, in some places, of masses, which in others constitute important rocks, seems often to point to a cause of their absence in removal after deposition, rather than to thinning out from want of matter, or being beyond the reach of the transporting power. We have, in the case of the Oriskany sandstone in New York, an example of this kind, where the mass does not apparently thin gradually, but terminates abruptly, and appears beyond this point in patches, as if it had formed outliers previous to the deposition of the superincumbent masses. The evidence of its destruction is not only indicated in this way, but by the presence of rounded masses, forming pebbles upon its surface, and imbedded in the succeeding rock.

It is not in this rock alone where we have indications of removal subsequent to deposition. In the western part of New York, the strata associated with the Oriskany sandstone bear equal evidence of having been acted upon by such forces, and the result has been their partial or total destruction. In some instances, the surfaces remaining are furrowed and channelled, as by the wearing action of a powerful current, and they present inequalities similar to the rocky bed of a stream or river. In no case of this kind, however, have I been able to detect the grooved and striated surface so common on our present rocks, the general appearance and the absence of masses being the strongest ground for this inference.

In the existence of wave lines we have conclusive proof of the existence of a sea-beach at this early period of the earth's history; a period when the ocean is supposed to have held universal dominion over the surface. And, although it may not indicate any great extent of dry land, still it points to the operations which at different subsequent periods have elevated these older deposits, and to which the existence of our continents is due. These, in conjunction with the ripple-mark, the foot-print, the impression of rain-drops, furnish us with evidence, that the early condition of land and sea was, in some degree, similar to the present; at least, that tides and waves, that currents and winds were then in operation, as at present. And the existence of these phenomena points us also to other facts; for the currents were produced by inequalities of bottom, or the proximity of land, as the winds were probably due to inequalities in the surface above the ocean, and rain was only produced by mountains or high lands, which would condense the vapor.

As a class, all these phenomena adduced, aid us in determining the conditions under which deposits were actually made, while all the subsequent modifications are indicated by other phenomena. These, together with the character and condition of the fossils of the strata, may be found important auxiliaries in our investigations, and aid us in determining the great problem of the condition of the surface at remote periods, and the comparative extent of sea and land.

An Inquiry into the Origin of the Appalachian Coal Strata, Bituminous and Anthracitic. *By Henry D. Rogers, Professor of Geology in the University of Pennsylvania, Philadelphia.*

INTRODUCTION.

The design of the present paper is, to exhibit, in a condensed shape, some of the most characteristic phenomena of the great coal formation of the Appalachian region of the United States, to develope the laws which regulate the distribution and order of succession of the strata, and to discuss the theory of their origin. But it is not intended to embrace a detailed description of our extensive and diversified basins, a full account of which is reserved for a future opportunity.

In prosecuting this investigation, though I have relied principally on my own observations, made during several years past in Pennsylvania and Ohio, and on those of my corps of assistants, attached to the geological survey of the former State, I have received much valuable information concerning western Virginia from my brother, Professor William B. Rogers, whose researches have enabled him to test the correctness of most of my conclusions. To him, and to Mr. C. Briggs, now connected with the survey of Virginia, but formerly with that of Ohio, I am indebted for my knowledge of the range and outcrop of the great Pittsburg seam in those States; while to my brother I owe the opportunity of making a highly instructive comparison in detail, of the coal strata of Pennsylvania with those of western Virginia. For some data respecting the positions of the limestones of the Ohio coal measures, I wish to acknowledge my obligations to the laborious paper of Dr. Hildreth, in the twenty-ninth volume of the 'American Journal of Science.' I have made a similar use of the Reports of Messrs. Briggs, Whittlesey, and Foster, on the geology of the same State. My attention was first directed to the marine character of some of the Appalachian coal strata, by the description of two or three fossils from the carboniferous rocks of the Allegheny mountains, by Mr. Conrad.* Other memoirs have appeared upon local portions of the coal region of Pennsylvania, but I am not aware that their details have contributed to any of the general laws and results here presented.

Of the Limits of the Appalachian Coal Strata.

The extensive Appalachian coal formation, embraces all the detached basins, both anthracitic and semi-bituminous, of the mountain chain of Pennsylvania, Maryland, and Virginia, and also the vast bituminous trough, lying to the northwest in Pennsylvania, Ohio, Virginia, Kentucky, Tennessee, and Alabama. I shall endeavor presently to show, that all these coal-fields, extending from the northeastern counties of Pennsylvania, to the northern part of Alabama, and from the great Appalachian valley, westward into the interior of Ohio and Kentucky, include only a portion of the original formation, immense tracts having been destroyed by denudation. A comparison of the coal strata of contiguous basins, has convinced me, that they are only detached parts of a once continuous deposit; and the physical structure of the whole region most satisfactorily confirms this idea, by showing that they all repose conformably on the same rocks; the more or less insulated troughs in which they occur, merely being separated by anticlinal tracts of greater or less breadth, from which denuding action has removed the other portions of the formation. This distribution of the coal in a series of parallel and closely connected synclinal depressions, is a direct result of the system of vast flexures, into which the whole of the Appalachian rocks have been bent, by the undulatory movements that accompanied the final elevation of the strata, and terminated the era of the coal.

Many of the general phenomena about to be described, seem to belong, in an equal degree, to the wide coal basins of equivalent age, which lie remote from the Appalachian chain, far to the northwest, namely, that of the State of Michigan, and that which occupies a part of Indiana, Illinois, and Missouri. I shall

*See Trans. Geo. Soc. of Pennsylvania, 1835.

confine my views for the present, however, to the formation as it is developed in the mountain basins, and in the great trough or plain which lies immediately to the northwest of the chain. This last, most western, or chief Appalachian basin, terminates on the northeast, near Towanda, in Bradford county, Pennsylvania, while its southern point is near Huntsville, in Alabama. The southeastern margin coincides nearly with the main escarpment of the Allegheny mountain, as far south as the county of Hardy, in Virginia, beyond which it lies further to the northwest, following as it ranges through that State, and through Tennessee, the great line of escarpment locally named Laurel Hill, Rich mountain, Little Gauly mountain, Great Flat Top, and Cumberland mountain, ending with the termination of the last in northern Alabama.

The opposite or northwestern outcrop, commencing likewise at Towanda, extends nearly westward through the northern counties of Pennsylvania to the Allegheny river, at Warren. It here begins to curve gently southward, passing through Crawford and Mercer counties, and enters Ohio north of Sharon. Beyond this its general course is about west-southwest to Akron, where it deflects to the south, so as to pass about twenty-five miles west of Zanesville, after which it crosses the Ohio river a few miles above the mouth of the Scioto. Southward from this point the western line of the coal traverses Kentucky in a south-southwest direction, passing the Kentucky river near the centre of Estil county, and the Tennessee line a little east of Rock creek. Ranging through Tennessee, its course is rather irregular, first running southward to Montgomery, thence northwestward to Morgan, and thence by a winding line southward to Sparta, beyond which it stretches southwestward to the termination of the Cumberland mountain, northeast of Huntsville.

This enormous tract of the coal formation is unbroken, except in two quarters; first, near its northeastern termination, and along its northern border in Pennsylvania, where by the influence of denudation, and a few low anticlinal arches, many small patches of the strata lie insulated from the general mass; and, secondly, along its southeastern side in Pennsylvania, Maryland, and Virginia, where a few bold axes of elevation have thrown the coal rocks into a series of long, parallel, and nearly united troughs. Considering all of these outlying portions of the formation as subordinate and intimately connected parts of one great bituminous coal-field, the southeastern boundary of which is the escarpment of the Allegheny and Cumberland mountains, the dimensions of the great basin will be nearly as follows: Its length, from northeast to southwest, is rather more than seven hundred and twenty miles, and its greatest breadth about one hundred and eighty miles. Upon a moderate estimate, its superficial area amounts to sixty-three thousand square miles.

There are besides this, however, several smaller basins which lie to the southeast, and are entirely separated from it. These consist of the detached troughs of anthracite, in eastern Pennsylvania, and the solitary outlying basin of semi-bituminous coal in Broad Top mountain, near the Juniata river. The total area of the coal strata in the anthracite district, may be approximately stated at about two hundred square miles, while the semi-bituminous formation of Broad Top is comparatively limited.

Though the deep anthracite basins abound in curious structural features, and contain thick seams of coal, they chiefly interest us at present, by the geographical position which they occupy. More than forty miles distant from the general denuded margin of the main or western coal-field, they nevertheless present, in the character of their strata, and of the rocks upon which they repose, unequivocal evidence that they and the bituminous basins were once united. In this identification, we are presented with an amazing picture of the former extent of our carboniferous deposits. The existing southeastern limit of the coal, in these insulated basins, lies, in Pennsylvania, only a short distance to the northwest of the great Appalachian valley, and a survey of all the circumstances involved in the question of the ancient physical geography of the formation, convinces me that it extended, both in that State and Virginia, at least as far to the southeast as that valley. To enter here into all the facts and reasonings upon which this inference is founded, would lead me aside from the main purpose of the present paper; but I may mention, as one argument, that a group of coal strata, somewhat lower in the formation than the main series, does reach, at intervals, as far eastward as the margin of the great valley, in a number of localities between the Potomac river and the Tennessee line. Restricting our attention, at present, however, to those districts where the main coal series is developed, we meet with the most ample proofs that all the strata in the insulated basins are precisely on the same geological horizon, as those of the great basin west of the mountains. These coal rocks all repose conformably on the same easily recognized formation, the great coal conglomerate, with the upper beds of which the lower seams are very generally interstratified. This fact, but more especially the circumstance that I have traced many of the principal coal seams and beds of fossiliferous limestone from basin to basin, fully demonstrates that all these detached troughs, however insulated and remote from the main mass at present, were, at the period of their deposition, united in one continuous formation, which, previously to its elevation and waste by denuding currents, extended from nearly the eastern side of the Appalachian chain, to a western margin, at least as distant as the centres of the States of Ohio, Kentucky, and Tennessee.

Here then we have a coal formation, which, before its original limits were reduced, measured, at a reasonable calculation, nine hundred miles in length, and in some places more than two hundred miles in breadth. I would ask, is it conceivable, that any lake, bay, or estuary, could have been the receptacle of a deposit so extended, or that any river or rivers could have possessed a delta so vast? The ancient Appalachian ocean grew deeper, as I shall show, towards the west or northwest, and inasmuch as rivers push their deltal deposits seawards, and not laterally, and as the carboniferous sediments here to be described are traceable coastwise, as respects this ancient sea, for a length of nine hundred miles, it is inconceivable how any local fluviatile currents could have assembled them.

My chief object in the present memoir being to exhibit the leading phenomena, which bear immediately on the discussions connected with the origin of this and other coal formations, I shall not here attempt a minute description of all the carboniferous rocks; and, to confine these remarks within as small a compass as possible, I shall restrict them to the main or upper coal measures, since these are the beds which best display the physical conditions under which the strata were accumulated.

Nature of the Coal Strata.

Assuming it as susceptible of demonstration, that all the various coal basins, bituminous and anthracitic, of Pennsylvania, Ohio, Maryland, Virginia, Kentucky, and Tennessee, were, as above stated, originally united, we may consider the whole as one great formation, in which some highly interesting gradations in the type and composition of the beds may be traced. To call attention to these phenomena of variation is indeed the main object of this paper, since by them only can we arrive at a true theory of the conditions under which the whole were formed. A comprehensive classification of the strata, shows the following principal varieties.

1. Rocks of mechanical origin, of every grade of coarseness, from the smoothest fire-clay, to exceedingly rough siliceous conglomerates, the whole including within these extremes a wide variety of shales, marls, argillaceous sandstones, and quartzose grits.

2. Limestones, both pure and magnesian, in strata of all thicknesses, from thin bands and narrow layers of detached nodules, to beds measuring from fifty to one hundred feet in depth. Some of the limestones contain a considerable amount of argillaceous and siliceous matter, and many of the thicker deposits consist of alternating layers of limestone and soft shale. Though a few of these calcareous strata are remarkably destitute of fossils, they are rarely found to be altogether deficient in organic remains, when widely and diligently searched; and some of them quite abound in them. It is especially deserving of note, that the genera are such as invariably indicate oceanic habits. This fact is of the more importance, since some of the limestones occur in immediate contact with beds of coal, and with shales and other strata containing the remains of terrestrial vegetation.

Besides the strata of limestone, we meet with other chemically formed deposits, in the form of numerous seams of carbonate of iron, and a few considerable beds of regularly stratified chert. The nodular variety of the iron ore is usually imbedded in shale, and lies oftenest adjacent to the coal, while the ore in bands occurs more frequently in contact with the limestone.

3. Coal, in nearly all its known varieties, including every description, from the dryest and most compact anthracites, to the most fusible and bituminous kinds of common coal.

Such are the three great classes of strata, comprised within the Appalachian coal region of the United States. If we direct our attention to the manner of their distribution, we shall behold some striking and instructive phenomena, susceptible of reduction to regular and harmonious laws of gradation.

Comparing, in the first place, the rocks of mechanical origin, as they occur in different districts, we almost invariably find them coarsest and most massive towards the southeast, and more and more fine-grained and less arenaceous, as we pursue them across the successive parallel basins northwestward. Thus in the anthracite coal-fields, which are the most southeastern of all, the coal is interstratified with a vast thickness of rough and ponderous grits, and coarse siliceous conglomerates; but is associated with comparatively very little soft clay slate or shale. In this region, the coal slates themselves, are more than ordinarily arenaceous, and bear a smaller proportion to the sandstones, than in the basins more to the west. At the same time that the coal rocks, viewed in the aggregate, acquire a finer texture, in going westward, the individual strata undergo a corresponding reduction in thickness, while many of them entirely thin away. I may cite, as a striking instance of these changes, the great coal conglomerate itself, which forms the general base of the main or upper coal measures. This massive rock is chiefly composed of large quartzose pebbles, imbedded in coarse sand. Adjacent to its most southeastern outcrop in Pennsylvania, that is to say, in the Sharp Mountain, where it constitutes the boundary of the first or Pottsville basin, it has a thickness of nearly fifteen hundred feet; but in the mountains which embrace the Wyoming coal-field, about thirty miles to the northwest, the thickness of the formation is only about five hundred feet; while still further across the chain, where it becomes the general floor of the coal measures under the bituminous form, in the basins northwest of the Allegheny mountain, its entire thickness seldom exceeds eighty or one hundred feet. Tracing it across the great western coal-field, until we encounter its last outcrop in western Pennsylvania, Ohio, and Kentucky, this wonderfully expanded rock, dwindles to a thin bed of sandstone, sprinkled with a few pebbles, its whole thickness amounting generally to only twenty or thirty feet. There is a corresponding and quite as striking a diminution in its constituent fragments, the pebbles in the most southeastern belts of the formation being often as large as a hen's egg; while in the northwestern, their diameter is reduced to that of a pea.

A similar gradation obtains in the thickness and coarseness of nearly all the interstratified sandstones and other mechanical members of the formation. I conceive that this interesting fact, fully established by the surveys of Pennsylvania and Virginia, shows beyond all question, that the southeast was the quarter whence the coarser materials of the coal rocks were derived. But there are not wanting other proofs that the ancient land lay in that direction. These will be presently detailed in describing the gradations witnessed in the limestones and beds of coal. The above general law of distribution, relates, it should be observed, only to the coarser mechanical aggregates, since there are some apparent exceptions to its generality, among the finer-grained slates and shales. Though the texture of these continues to grow finer as we advance westward, some of the strata, when individually traced, seem to increase for a certain distance in thickness. This curious circumstance, which belongs indeed to many of the more argillaceous members of our Appalachian formations, so far from invalidating the above inferences respecting the westward transportation of the sediments, comes beautifully to confirm them, since it is evident, that until a current, holding in suspension a quantity of sedimentary matter, declines in velocity to a certain point, it cannot let fall any considerable amount of the smaller particles. After it has reached a given degree of retardation, the finer materials will subside, and in an increasing quantity, up to a certain point, at which the loss of velocity in the current is compensated by the exhaustion of material, when a gradual and final thinning of the deposit will take place.

If we examine, in the next place, the gradations of thickness visible in the limestones and other marine deposits, they will be found to lead to precisely similar inferences respecting the position of the ancient land. Viewed either together or individually, the limestones of the coal-measures of Pennsylvania, Virginia, and Ohio, display a remarkably uniform augmentation, as we trace them westward. Thus, throughout all the southeastern basins, comprising the whole of the anthracite coal-fields of Pennsylvania, and the Broad Top mountain in the same State, the formation exhibits a total absence of limestone, and a corresponding deficiency of calcareous matter in the shales and the iron ores. Advancing, however, a distance of twenty-five or fifty miles northwestward, to the general southeastern margin of the great bituminous region, where we enter on the first of the chain of partially insulated troughs adjacent to the escarpment of the Allegheny mountain, we no longer encounter a total poverty of limestone, though we still meet with a striking deficiency. As an evidence of this, let us take one of the basins of the Allegheny mountain, that, for example, which lies near the head of the Potomac river. The minute researches there made, in connection with the geological surveys of Virginia and Pennsylvania, have shown that the total thickness of the limestones, counting all the thin bands and layers of nodules, does not probably exceed ten feet. This statement is confirmed by a pamphlet on the same coal-field, describing the land of the George's Creek Company, by Messrs. Alexander and Tyson. In their very full section of the strata, we do not see a single band of limestone introduced.

Turning to the Moshanan basin, in Centre county, which is also a marginal trough of the great western coal-field, the entire quantity of limestone appears to be about seven or eight feet. If, however, we pass westward from this southeastern line, and cross the great coal-field by any section, between the Susquehanna in Pennsylvania, and the Little Kenawha in Virginia, we witness a regularly progressive expansion of the calcareous rocks. In the following tabular statement, which refers chiefly to the southern counties of Pennsylvania, this gradation is rendered strikingly obvious.

TABLE FIRST,

Showing the gradual Increase in the aggregate thickness of the Limestone, as we cross the Southern Coal-fields of Pennsylvania, westward.

Broad Top basin; half way across the Appalachian chain,	*none.*
Potomac basin; near the main escarpment of the Allegheny mountain,	about 10 feet.
Eastern basin of Somerset county, west of the escarpment, and about twelve miles west of the Potomac basin,	12 feet.
Ligonier basin, twenty miles west of the last,	30 feet.
Second western basin, on the Youghiogheny river, fifteen miles west of the last,	about 40 feet.
Great basin of the Monongahela and Ohio rivers, at Brownsville, probably,	60 feet.
Same basin at Wheeling,	about 200 feet.

The above aggregates admit the more accurately of comparison, since most of them refer to the same portion of the formation, that, namely, which is included between the great conglomerate, and the top of the main limestone, above the Pittsburg coal-seam.

TABLE SECOND,

Showing the Gradation in the thickness of the large Limestone stratum, overlying the Pittsburg Coal-seam.

Cumberland basin; not more than	2 feet.
Eastern Somerset basin, not determined, but	thin.
Ligonier basin,—average about	7 feet.
Monongahela and Ohio basin, at Brownsville,	41 feet.
Same basin at Wheeling,	54 feet.

In the upper coal group, or that part of the series which commences with the Pittsburg seam, the total thickness of pure limestone, excluding numerous thin bands, associated with some of the layers of shale, is not less than one hundred and fifty feet.* Some of the limestone strata of the coal-measures, possess, as will be seen from the second of these tables, a remarkably wide dis-

* See Report on Geological Survey of Virginia, for 1840.

tribution, ranging without interruption from the vicinity of the Allegheny mountain, to the country west of the Allegheny river. Having ascertained the positions of a number of these fossiliferous beds, I am now engaged in investigating their organic remains. The examinations already made, show that these all belong to *marine* genera, and that the different beds are characterized by their peculiar species. Many of these beds of limestone have been traced continuously from northern Pennsylvania to the Kenawha, and from the eastern outcrop, near the Allegheny mountain, to their western boundary in Ohio. The marine character of their genera, — *Terebratula*, *Goniatites*, *Bellerophon*, *Encrinus*, &c., sufficiently proves that these rocks were originally deposited beneath the waters of an ocean, while at the same time the increasing purity of the limestones, and the multiplication and expansion of the beds westward, clearly show that the ancient ocean augmented regularly in depth in that direction. This conclusion, it will be observed, agrees strictly with the results before deduced from the general gradation, visible in the sandstones and other mechanically formed rocks, which proves that the ancient land was situated towards the east or southeast. If we examine the relations of the two classes of the coal-strata to each other, the land-derived and sea-derived rocks, we perceive that the latter, or the limestones, thicken, going west at the expense of the former. Frequently, two beds approach, and either entirely coalesce, or remain divided by only a thin, marly shale, formed from the residual, finely subdivided matter, wafted out by the currents, which, further eastward, or nearer the land, deposited the coarser and thicker sandstones and arenaceous slates. While this gradation shows itself, new beds of calcareous rock interpolate themselves in new positions in the series, and many of the sandstones thin away and cease altogether, so that the whole formation becomes, by both these changes, more and more oceanic in its type. But the most important result of this mode of tracing the strata, is the evidence we have of the frequent alternation of a tranquil and disturbed condition of the waters. Such an intermission of movement and repose will be more fully proved, when I come to describe the phenomena connected with the coal-seams. It may be sufficient here to refer to what I have above stated, respecting the oceanic and shore rocks, and to appeal to the argument that the coarser or more irregularly strewn the materials of a stratum are, the more violent must have been the current which transported them. With these considerations before us, we cannot fail to perceive, in the Appalachian coal-strata, the monuments of many alternate periods of movement and total or comparative rest. If it be conceded, that each of the purer beds of limestone, remarkable for the extreme fineness of their texture, and the absence of foreign sedimentary matter, is the index of a longer or a shorter interval of tranquillity in the waters, we shall discern (omitting for the present all similar inferences to be derived from the coal-seams) a much greater number of such separate periods, than a mere enumeration of the individual beds would indicate, unless we attend to the interstratified shales and marls. These last-mentioned strata, generally assuming, as we go eastward, a thicker and coarser type, furnish as unequivocal a record of disturbances, as if the spaces they occupy between the beds of limestone, were filled by the coarsest mechanical aggregates.

One of the most interesting general questions connected with the land and sea-produced strata, relates to the physical geography of the ancient coast, near to which they were deposited, and the inquiry at once suggests itself, whether the receptacle of these various sediments was an extensive estuary, receiving the silts of some gigantic river or rivers, or a vast expanse of shallow sea, bounded by a long line of coast, upon which the successive deposits were formed by a very different agency from any we can ascribe to ordinary fluviatile or littoral currents.

Of the Phenomena connected with the Coal-Seams.

Great extent of certain individual coal-beds. Passing, in the next place, to an examination of the most interesting portion of the coal strata, the coal-seams themselves, we discover in the facts connected with their range and distribution, in the structure of the coal, and in the nature of the beds in immediate contact with the seams, several general laws, tending to afford us a still better insight into the physical conditions which accompanied the production of these strata.

Of the facts connected with the range of the individual coal-seams, that of their prodigious extent is, itself, one of the most surprising and instructive. As a general rule, this wide expansion characterizes all the beds of both the bituminous and anthracitic basins. It is true, that many seams possess a comparatively local range, but not a few of those which, on first examination, appear of circumscribed extent, cover in reality a very wide area, the error respecting them being caused by fluctuations of thickness, or by their occasionally thinning out and reappearing. Among those which manifest great permanency as to thickness, the vast range of some of the larger ones is truly extraordinary. Let us trace, for example, the great bed, which occurs so finely exposed at Pittsburg, and along nearly the whole length of the Monongahela river, and which I have called the Pittsburg seam. The high position which this bed occupies in the formation, and the nearly horizontal attitude of all the strata, combine to expose it very extensively to observation, while its great size, and the excellence of the coal, have caused it to be generally mined. After identifying and tracing it from basin to basin in Pennsylvania, I have been furnished with much information in relation to its limits and features in Virginia and Ohio, by my brother and Mr. Briggs. Guided by the data thus collected, I have been enabled to determine its area and boundaries with very considerable accuracy. The limits of this bed, as at present known, are nearly as follows. That portion, by far the largest part, which is contained in the great western basin, has its northern termination in Indiana county, in Pennsylvania, and its southwestern on the Ohio river, below Guyandotte. The general southeastern outcrop ranges along the western foot of the Chestnut ridge, or West Laurel hill, from Indiana county to Tygart's river, in Virginia. It here alters its strike from south-southwest to a direction more nearly south, passing a little west of and parallel to, Buchanan's river, until it nearly gains the head-waters of the Monongahela. From this point its course is more winding, but the general direction is a little west of southwest to the Great

Kenawha, which it crosses between Charlestown and the Pocatalico creek. From the Kenawha, it ranges nearly west to the Ohio river, between Guyandotte and Burlington, where, crossing that great stream into the state of Ohio, it sweeps rapidly north. Its outcrop, now following the western margin of the basin, preserves a general north-northeast direction as far as McConnelsville, on the Muskingum. Beyond this point it stretches in a northeasterly course, until it recrosses the Ohio river a little above Steubenville, where it soon reaches the western line of Pennsylvania, in Beaver county. Here the edge of the seam turns eastward, and crosses the Ohio river once more, a few miles below Pittsburg, and the Allegheny river, some miles northeast of that town. East of this point, it pursues a more devious line, the meanderings of which are caused by three parallel anticlinal axes, crossing the Kiskiminitas and Conemaugh rivers. Being thrown into a very irregular and curving outcrop by these elevations, it finally joins the southeastern margin, at the northeast extremity of the basin, in Indiana county, the point from which we set out. The longest diameter of the great elliptical area here delineated, is very nearly two hundred and twenty-five miles, and its maximum breadth about one hundred miles. The superficial extent of the whole coal-seam, as nearly as I can estimate it, is about fourteen thousand square miles.

But the limits here described, though wide, fall very far within those which the bed anciently occupied. To the southeast of the large basin of the Ohio river, there are several other insulated, parallel troughs, which also contain the Pittsburg seam. Of these, the furthest from the main coal-field is that at the head of the Potomac river, at a distance of about forty-three miles in a straight line. The eastern margin of the Pittsburg bed is here, however, nearly fifty miles east-southeast of the eastern edge of the same seam, in the main or western basin, and it has a corresponding expansion eastward, in other districts. That this coal-bed preserves an unbroken range for many miles to the northeast of the termination of the principal basin, in Indiana county, appears highly probable, from a comparison of the coal-measures at certain localities in that quarter. I shall not, however, assume the known length of the tract actually occupied by it, as exceeding the above-mentioned two hundred and twenty-five miles, throughout which it is uninterruptedly traceable. If we now take into account the fifty additional miles of breadth which the bed once possessed, its former area must have been at least thirty-four thousand square miles, a superficial extent greater than that of Scotland or Ireland.

Though the above is, perhaps, the greatest extent of surface, which it is in our power positively to assign to this bed of coal, the proofs of a prodigious denudation of the strata, throughout the districts bordering its present outcrop, are so irresistible, that I consider the dimensions here given as bearing actually but a small proportion to the real ancient limits of the stratum. I consider it, indeed, probable, that this seam is identical with the great bed which occurs in all the anthracite basins, and which displays a similar degree of constancy in its features. Opportunities for research have not yet occurred to enable me, however, to produce evidence as to this point, of a sufficiently conclusive character. Should such an identity be established, we shall then behold, in all its conditions of gradation from anthracite to semi-bituminous and highly bituminous coal, a single stratum, measuring, at the most moderate calculation, four hundred and fifty miles in length, and two hundred miles in breadth, and covering a space of at least ninety thousand square miles. But, restricting our attention for the present to those limits, which it did undoubtedly once occupy, it is still by far the most extensive coal-bed yet explored in any country, and the mere fact of its great extent must exert an influence on our views concerning the conditions under which the whole coal-formation originated.

The general uniformity in the thickness of this superb bed, throughout so vast a region, and at the same time the regular and gentle gradation which it experiences in size, when we trace it from one outcrop to the other, are features not less remarkable than its enormous length and breadth. In the most southeastern basins, where it is most developed, its total thickness is from twelve to fourteen feet; while in the basins between the Chestnut ridge and the Monongahela river, it usually measures from ten to twelve feet. Still further to the west, between the Monongahela river at Brownsville and the Ohio at Wheeling, it declines from about ten to eight feet, and beyond this, in the state of Ohio, it seldom exceeds five or six feet. Following it longitudinally, or in the direction of the great elliptical basin, it displays quite as remarkable a persistency in its dimensions, the reduction in its size being, if any thing, still more gradual from northeast to southwest. Thus at Pittsburg it measures, altogether, about eight feet; at the mouth of Big Grave creek rather more than five; on the Great Kenawha about five; and from this point to Guyandotte, where it terminates, three feet; and, finally, hardly two feet. Tracing it along a parallel line, from northeast to southwest, but nearer its southeastern outcrop, we detect the same very gradual abatement in its thickness. While we are thus furnished with conclusive evidence, from the fact that its rate of increase is most rapid towards the southeast, that the ancient land with which the stratum was connected must have been situated in that direction, we see that the northeastern part of the coast was the quarter where its materials were supplied in the greatest abundance. To this conclusion I am disposed to appeal, in support of the conjecture already ventured, that this great bed of the main or western coal-field, is but a remnant of a still more expanded stratum, which attained its maximum size, in the enormous seam of which all the anthracite basins present us insulated patches. The singular constancy in the thickness of this Pittsburg bed, no less than its prodigious range, are circumstances that seem strongly adverse to the theory which ascribes the formation of such deposits to any species of *drifting* action. But a more thorough discussion of this question will be attempted presently.

Of the intimate Mechanical Structure of the Coal.

An examination of the structure of the coal itself, apart from the fact of the great range and uniformity in the thickness of the beds, renders it apparent, that no irregular dispersion of the vegetable matter by any conceivable mode of drifting, either into estuaries, or the open sea, could produce the phenomena which they exhibit. The mechanical arrangement of the layers in every coal seam, as seen when viewed edgewise, indicates plainly, that it is a compound stratum, as much as any other sedimentary deposit, each bed being made up of innumerable very thin laminæ of glossy coal, alternating with equally minute plates of impure coal, containing a small admixture of finely divided earthy matter. These subdivisions, differing in their lustre and fracture, are frequently of excessive thinness, the less brilliant leaves sometimes not exceeding the thickness of a sheet of paper. In many of the purer coal-beds, both anthracitic and bituminous, these thin partings between the more lustrous layers, consist of little laminæ of pure fibrous charcoal, in which we may discover the peculiar texture of the leaves, fronds, and even the bark of the plants which supplied a part of the vegetable matter of the bed. If traced out to their edges, all these ultimate divisions of a mass of coal will be found to extend over a surprisingly large surface, when we consider their minute thickness. Pursuing any given brilliant layer, whose thickness may not exceed the fourth part of an inch, we may observe it to extend over a superficial space which is wholly incompatible with the idea, that it can have been derived from the flattened trunk or limb of any arborescent plant, however compressible. When a very large block of coal is thus minutely and carefully dissected, it very seldom, if ever, gives the slightest evidence of having been produced from the more solid parts of trees, though it may abound in fragments of their fronds and deciduous extremities. The laminæ of brilliant carbonaceous matter almost invariably thin away to a fine edge before they terminate, a fact which of itself seems to prove, that the material was in a soft or pulpy state at the time of its accumulation, and this supposition receives countenance from the homogeneous texture and conchoidal fracture of every such layer.

Granting the correctness of this inference, which is not in conflict with the beautiful microscopic determinations, by Hutton, respecting the traces of vegetable structure in certain portions of coal, the argument seems almost conclusive, that the vegetable matter grew where it was deposited. It is difficult to understand why the coal should not consist, principally, of the larger parts of trees, such as their trunks, limbs, and roots, if any species of drifting operation brought together the materials of the bed, by conveying seawards the growth of ancient forests. The leaves, and other fragile parts, would soon become detached on the voyage, and these, together with the smaller plants, would subside and get imbedded, long before the trunks and lighter woody parts could grow sufficiently water-logged to sink. It is obvious, that a stratum formed by the successive deposition of huge irregular stems and branches, would exhibit, no matter what might be the subsequent pressure, a very different structure from that thin and uniform lamination, which distinguishes all beds of coal. These considerations, derived from the mechanical features of every seam of coal, receive strong confirmation from the microscopic researches of Mr. Hutton. Though that observer found more or less of the cellular vegetable structure in each of the three varieties of Newcastle coal, he discovered a complete obliteration of the characteristic cells in those finest lustrous portions of the caking coal, where the crystalline structure, as he terms it, is best developed. Besides the above-mentioned features, all the coal-beds which I have ever examined or seen minutely described, possess another peculiarity in their mechanical constitution, on a less minute scale, which is equally incompatible with the notion of a transportation by currents. I refer here to the subordinate divisions of the coal-beds, some of which are strata of pure coal, some of earthy coal, and some of common shale, all constituting together the compound mass, which we call a coal-seam, but each maintaining its particular position and character as a distinct deposit over an area which is truly astonishing. Those persons who are conversant with large mining districts are aware of the many instances of remarkable persistency in these subdivisions in the coal-beds, since it is frequently by their means that the miners recognize a known coal-seam in cases of difficulty. Thus the largest bed of the anthracite fields of Pennsylvania contains, almost every where, a particular band of unusually pure coal, not far from the bottom, generally from three to four feet in thickness. A still more striking example occurs in the great Pittsburg bed, already spoken of. If we dissect this compound mass, and trace the several divisions, we become impressed with the wonderful distances to which some of them extend. Not to enter here into a minute discussion of all the features of this widely distributed seam, it will suffice to state, that it consists principally of three members, which are readily recognized. The lowest is a thick bed of uncommonly pure coal, the middle a layer of soft shale or fire-clay, about one foot in thickness, and the uppermost or roof coal is itself a compound seam, two or three feet thick, of alternating layers of coal and fire-clay. Now it is a highly instructive fact, that this general triple subdivision prevails throughout nearly the whole range of the seam from its eastern to its western outcrops, and from the Conemaugh, in Pennsylvania, into Western Virginia, for a distance of more than two hundred miles, from northeast to southwest. But besides this fact, each subordinate portion preserves its own distinctive features, the upper member being every where remarkable for its alternation of thin bands of coal and shale. Can any evidence be more conclusive as to the uniformity of the conditions under which every part of this coal-bed was produced? There must, indeed, have prevailed an almost perfect uniformity in the state of the surface throughout the vast area which it occupies, as respects even the formation of the thinnest of these subdivisions. Such remarkable sameness of action throughout the same geological horizon, appears absolutely incompatible with any mode of drifting of the vegetable matter. Only one particular process of accumulation promises to explain the occurrence in such cases, of these thin and uniform sheets of material, of which the thickness is often less than a foot, while their superficial area is many hundred square miles. I cannot conceive any state of the surface, but that in which the margin of the sea was occupied by vast marine savannahs of some peat-creating plant, growing half immersed on a perfectly horizontal plain, and this fringed and interspersed with forests of trees, shedding their offal of leaves upon the marsh. Such are the only circumstances, under which I can imagine that these regularly parallel, thin, and widely extended sheets of carbonaceous matter, could have been accumulated.

Independently of the above argument, based on the breadth and uniform distribution of the layers in the coal, there is another, drawn from the striking deficiency of earthy sedimentary particles. In many of the purest layers, the total proportion by weight of foreign mineral substance, in the coal, is less than two per cent., sometimes barely one per cent., while the ratio by bulk is consequently less than one half of this. So extremely insignificant a quantity is what we should expect, on the hypothesis of a tranquil accumulation in wide sea-meadows, extending far out from the edge of the ancient shore, where no turbid currents could get access. It is as inconsistent, on the other hand, with the notion of a drifting of the vegetable matter itself, which, according to any conceivable mode of transportation, would be accompanied by a large amount of earthy matter, such as abounds in all deltal deposits, and even mingles with the wood in the raft of the Atchafalaya. That so nearly the whole of the suspended mineral matter, even to the fine particles of impalpable clay, should have subsided, in almost every instance, before the first portions of the floating vegetation sank, contradicts all observation respecting similar actions now occurring. The introduction of any argillaceous matter into the transparent waters of the great peat morasses, must have happened in the manner of an exceedingly quiet and diffused silting in, or more properly a slow intermingling, of very slightly turbid water with that of the limpid sea. The above arguments from the uniformity in the distribution of the vegetable matter of the coal-seams, and from the absence of earthy matters in the coal, have been already employed by Mr. Beaumont as objections to the drift theory, in a communication read to the Geological Society of London, February 26th, 1840.*

Of the Character of the Strata in immediate contact with the Coal-Seams.

Turning from the structure of the coal itself, to the character of the strata, usually in immediate contact with it, we discover certain prevailing relations, from which, by a careful study, much

* Beaumont, Proceedings Geol. Soc., No. 69.

light is to be derived both as to the statical conditions, and the order of the physical events which attended the production of the whole coal-formation. There is an interesting and characteristic difference, in point of composition and structure, between the beds bounding the upper and lower surfaces of every coal-seam. This, though of great significance in its bearings on the theory of the formation of coal, has never been distinctly examined with that view.

Of the material underlying the coal-beds. The deposit, upon which each seam of coal immediately rests, and which I shall call the floor, is, with a few rare exceptions, wholly distinct in its composition from the roof, or that which reposes directly upon the bed. To Mr. Logan we are indebted for having ascertained the highly important fact, that the floor of every coal-seam in South Wales is composed of a peculiar variety of more or less sandy clay, distinguished by its containing the *Stigmaria ficoides*. "Portions of the stem of the *Stigmaria* are found in other parts of the coal-measures, but it is only in the under clay, that the fibrous processes are attached to the stem, or associated with it." * Since the publication of his Observations on the Stigmaria Beds of South Wales, the same gentleman has extended his researches to the United States, and has found our own coal-seams in Pennsylvania to be similarly accompanied.† Mr. Lyell has also shown, that this peculiar stratum underlies the bituminous coal-beds at Blossburg, in Pennsylvania. I subsequently visited, with that eminent geologist, the anthracite beds of the Pottsville and the Beaver Meadow basins in Pennsylvania, where we found the Stigmaria bed, in the same position, below those seams. Still more recently, I have ascertained from my own notes on the geological survey of Pennsylvania, and from those of my brother in relation to Virginia, that this deposit accompanies nearly every coal-bed in the great bituminous region west of the Allegheny mountain. I shall take occasion presently, however, to point out some peculiar exceptions to its general prevalence. The theoret-

* Logan, Proceedings Geological Society, No. 69.

† Logan, Proceedings Geological Society, for April, 1842.

ical importance of this generalization concerning the Stigmaria, and the fire-clay inclosing it, appears to have been discerned by Mr. Logan, but he has not offered any explanation of the fact. The following passage, from the published abstract of his paper, conveys his views: "When it is considered, that over so considerable an area as the coal-field of South Wales, not a seam has been discovered, without an under-clay abounding in Stigmaria, it is impossible to avoid the inference, that there is some essential and necessary connection between the existence of the Stigmaria and the production of the coal. To account for their unfailing combination by drift, seems unsatisfactory; but whatever may be the mutual dependence of the phenomena, it affords reasonable grounds to suppose, that the *Stigmaria ficoides* is the plant to which we may mainly ascribe the vast stores of fossil fuel." I am not aware, that either Mr. Logan, or any other geological writer, has attempted to account for the great frequency of this stratum immediately underneath the coal, or that any hypothesis has been advanced to explain the general prevalence in it of the Stigmaria, and the absence of all those other species of plants, which abound among the layers of the coal itself, and in the roof, and other overlying rocks. One main object of the following theory of the origin of the coal-measures, is to attempt the solution of these curious facts: *

* Since this memoir was written, my attention has been called by my brother, Prof. Wm. B. Rogers, of Virginia, to the splendid work of Mr. Edward Mammatt, on the Coal-Field of Ashby de la Zouch, published in 1834. This elaborate description contains a clear announcement of an under-clay for almost every coal-seam, and mentions, moreover, the presence "of a distinct single vegetation" in that of the *main coal*, with other facts and suggestions, since confirmed by Mr. Logan, and several other recent writers, on the origin of the coal strata. I cannot find, that the obvious claims of Mr. Mammatt to priority, as a discoverer in this interesting subject, have been any where acknowledged. It is to be regretted, that the still earlier opinions of Werner, De Luc, and Adolph Brongniart, attributing the vegetable matter of the coal-beds to a growth on the spot where the coal now exists, should have escaped so generally the attention of British geologists, with the exception of Mr Lyell *

The following passages, from Mr. Mammatt's work, will convince us how very near he was to a clear conception of the relations of the Stigmaria, and to a sound doctrine of the circumstances, under which the coal-beds were accumulated. "Seams of fire-clay abound in the Ashby coal-field, and there are very few coal-measures (coal-seams?) which

* Since this paper was read, Dr. Buckland's admirable 'Anniversary Address to the Geol. Society of London, for 1841,' has appeared; in which he mentions, that this doctrine has been entertained by De Luc, McCulloch, Jameson, Brongniart, Lindley, and other writers.

The Stigmaria presented in its structure, according to Lindley and Hutton, a low, dome-shaped, fleshy trunk, or centre, from the edge of which there radiated a number of horizontal branches, supplied with a multitude of slender, cylindrical, and exceedingly long leaves. The fire-clay, or Stigmaria clay, as we may indifferently call it, abounds in these delicate leaves, in a flattened and distorted condition; and it is partly to them and partly to the comminuted state of the argillaceous material itself, that the stratum owes its characteristic tendency to crumble in every direction. The branches of the Stigmaria, which usually lie parallel to the plane of the stratum, and are most abundant nearest the coal, it has been suggested, were hollow cylinders, composed entirely of spiral vessels, and contained a thick pith. The plants, according to Dr. Buckland, probably floated on the water.

Of the Roof of the Coal.

If we examine, in the next place, the strata which immediately rest upon the coal, we shall discover a condition of things in striking contrast with the phenomena of the under-clay. Instead

do not rest upon it, as the Sections will show." And again. " From the circumstance, that so many cases occur, where a tolerably pure fire-clay lies immediately under, and in contact with, a bed of coal, it may be inferred, that such clay stratum could not have been the soil, where grew the vegetable matter which produced the coal, unless this vegetable matter was a moss, a peat, or some aquatic plant; because, in the clay, there is no appearance of trunks, or other vegetable impressions, beyond slender leaves, as of a long grass."

" The fact, that particular strata accompany the main coal for many square miles, would support the idea, that an immense flat was originally covered with the substance of this fire-clay, many feet thick, and that, upon this flat, there took place an uniform growth of a distinct single vegetation, which must have occupied the position for a long period, and thus furnished the substance which composes the *main coal.* The alternations of fire-clay and coal-seams would favor the notion, that these materials were originally mixed together in a fluid, and that those of the former, by their gravity, would first subside, whilst the vegetable matter, or those of the latter, would undergo a more gradual deposition. Hence, by a repetition of the process, the alternations of the strata would be produced. Besides, it may be supposed, that if the strata of coal have derived their origin from the growth and destruction of a forest, some portions of them would have been thicker than others, and altered in quality, or have retained, at least, some traces of forest trees; whereas, on the contrary, most extraordinary uniformity in quality, compactness, and thickness of the seams, prevails to a great extent." *

* Geological Facts, by Edward Mammatt, p. 73.

of one uniform material, almost invariably present, composed of finely divided particles, the beds overlying the coal consist of nearly every variety of rock embraced in the formation, though they are more usually some form of laminated carbonaceous slate. Both in composition and structure, the roof rock manifests signs of having been deposited by a more or less rapid current. In place of a single species of fossil plant, it usually includes a prodigious variety, and the delicate ramifications of these, instead of intersecting the bed in various directions, as the processes of the Stigmaria do in the fire-clay, lie in a singularly disordered and fragmentary condition, in planes almost invariably parallel to the bedding. Lindley and Hutton, in their work on the Fossil Flora of Great Britain, give the following very accurate description of the mode in which the organic remains occur in the roof slates in England, and the account is equally applicable to those of the United States: — "It is the beds of shale or argillaceous schistus, which afford the most abundant supply of these curious relics of a former world; the fine particles of which they are composed having sealed up and retained in wonderful perfection and beauty the most delicate forms of the vegetable organic structure. Where shale forms the roof of the workable seams of coal, as it generally does, we have the most abundant display of fossils. The principal deposit is not in immediate contact with the coal, but from twelve to twenty inches above it, and such is the immense profusion in this situation, that they are not unfrequently the cause of very serious accidents, by breaking the adhesion of the shale-bed, and causing it to separate and fall, when, by the operation of the miner, the coal, which supported it, is removed. After an extensive fall of this kind has taken place, it is a curious sight to see the mine, covered with these vegetable forms, some of them of great beauty and delicacy; *and the observer cannot fail to be struck with the extraordinary confusion, and the numerous marks of strong mechanical action, exhibited by their broken and disjointed remains.*" Such is the nature of the roof, when it consists of the usual carbonaceous shale or slate, but it is oftentimes a much coarser rock in the Appalachian coal-fields; being either an argillaceous flaggy sandstone, or a coarse arenaceous grit, or even, occasionally, a siliceous conglomerate. In these instances, the inclosed vegetable remains are for the most part fragments of the larger stems or branches of gigantic arborescent plants, their fronds and leaves being less abundant. These fragments occur in all postures, as respects the plane of the bedding, horizontally, obliquely, or perpendicularly; and betray, in their broken condition and irregular mode of dispersion, the sudden and tempestuous character of the currents which drifted and entombed them. Though the arenaceous rocks, having these features, sometimes rest in immediate contact with the upper surface of the beds of coal, they more frequently lie at a moderate distance over them, an argillaceous, laminated slate interposing to form the actual roof. A further indication of the violence of the currents, which strewed these coarse materials over the coal, is sometimes to be detected in the composition of the lowest portion of the overlying bed of grit or sandstone, in which a large amount of coal, in the state of powder or sand, is disseminated in the rock, giving it a dark, speckled appearance. This is of very common occurrence in the anthracite coal strata of Pennsylvania, where the coarse grit not unfrequently rests immediately on the coal. It implies, I conceive, the erosion of a certain portion of the upper surface of the soft, carbonaceous mass by the friction of the sandy current. The coaly matter, thus disturbed, would subside with the first layers of the sand, with which it was mingled. Mr. Logan has mentioned a still more striking proof of the energy of the movements which occasionally occurred, during the formation of the coal-measures. He gives an account of actual boulders, or rounded pebbles of coal, in the Pennant grit, and other coarse strata of the coal-field of South Wales.

Of the direct contact of Coal-Beds and Marine Limestones.

In the preceding account of the strata immediately below and above the seams of coal, I intentionally omitted to introduce the limestones, which occasionally compose the floor or the roof, sometimes in direct contact with the coal. The portion of the

Appalachian coal-formation, in which this remarkable contiguity of marine calcareous strata and vegetable or terrestrial coal occurs, is the great western basin of the Allegheny and Ohio rivers. I have already mentioned the abundance of unquestionably oceanic limestones in this coal-field, and given my inferences from the interesting fact, that they augment in thickness, and multiply in number, in crossing the region northwestward. As, however, the actual contact of beds of coal and limestone is of rare occurrence in the coal-fields of other countries, and as the circumstance must have an influential bearing on all our speculations concerning the physical conditions prevailing at the formation of the strata, and, to a certain extent, on our whole theory of the origin of coal, I shall here describe some of the best known instances before I reason concerning them.

Confining our attention to the great western basin, where the most striking cases occur, the following instances of this contact present themselves, in the ascending order.

1st. In the lower division of the main coal-measures, there occurs, near the town of Mercer, in Pennsylvania, a seam of good coal, having a thickness of about two feet, which is immediately overlaid by a bed of very pure limestone, also about two feet thick, containing a variety of marine organic remains of the genera *Terebratula*, *Bellerophon*, &c. In some spots, the pure coal is not separated from the pure limestone by more than a single inch, or at most two inches, and then the interval is filled with a calcareo-carbonaceous shale.

2nd. Higher in the series, but still in the lower part of the main coal-measures of western Pennsylvania, we meet with a bed of fossiliferous limestone, the thickness of which, in many neighborhoods, near the Allegheny river, is about fifteen feet. It contains several oceanic species, among them some *Crinoideæ*, two species of *Terebratula*, and a *Goniatites*. In some places, this stratum embraces a thin seam of coal, four inches thick, in almost direct contact with the limestone.

3d. The limestone, which is the first underneath the Pittsburg seam, contains a bed of coal one foot in thickness, separating two of its lower layers.

4th. Near Pittsburg, the great coal-seam frequently rests within a few inches of this underlying limestone, in which are a few occasional fossils, all of marine genera. In these places the dividing layer is only a few inches thick, and consists of a bluish fire-clay.

5th. In Fayette county, Pennsylvania, the great limestone, which lies above the Pittsburg coal-bed, incloses very generally two thin seams of perfect coal, immediately in contact with the layers of the rock. These coals appear to have considerable range, extending into the adjoining counties. The largest is occasionally two and a half feet thick, and a few inches of black calcareous slate alone separate it from the hard limestone. The other coal-bed has a thickness of about one foot, and its surfaces are in equally close contact with the limestone. Neither of these beds is as widely expanded as the including limestone.

6th. Underneath the uppermost workable bed of coal in western Pennsylvania, or that which I have termed in my Reports the Waynesburg seam, there is a stratum of limestone, which sometimes incloses a thin coal-bed, measuring about one foot.

7th. At Putnam Hill, near Zanesville, in Ohio, a bed of limestone, five feet thick, rests, according to Dr. Hildreth, on a seam of coal of one foot, there not being more than two inches of fire-clay interposed. The limestone contains *Encrini*, *Terebratulæ*, and other marine fossils.*

8th. The same writer mentions, that on the Clear Fork of Little Muskingum, in Ohio, there is a seam of good bituminous coal, three feet thick, reposing directly on a dark carbonaceous fossiliferous limestone, eight feet in thickness. It is overlaid by another limestone, measuring six feet, from which it is separated by a very thin layer of shale.

9th. Dr. Hildreth further states, that on Wills's creek, in the same region, a coal-seam, five feet thick, occurs, resting immediately on a bed of limestone, the thickness of which is twenty feet.

I might cite a large additional number of cases in Pennsylva-

* Hildreth, in American Journal of Science, p. 31.

nia, Virginia, and Ohio, in proof of the frequency of the contact of the coal-seams and beds of limestone; but I have been disposed to establish the fact, chiefly, from instances in different portions of the formation, and to show, that the contiguity of the coal and limestone is often maintained throughout a considerable extent of country.

THEORY OF THE ORIGIN OF THE COAL STRATA.

Having presented what, I trust, is a sufficiently full sketch of the leading phenomena of the Appalachian coal-measures, and shown their correspondence, in several essential features of structure, to the coal-formation of Europe, I shall proceed now to consider what inferences we are entitled to draw respecting their origin, and that of the coal-formation generally. But, before taking this theoretical survey, it will be expedient to state, succinctly, the views of the several eminent geologists, who have recently written on this subject. I feel it the more incumbent to do this, since some of the speculations I shall advance are but modifications of hypotheses already published.

From a passage in Mr. Lyell's admirable work on the Elements of Geology, it appears, that M. Adolphe Brongniart, after comparing the phenomena of the ancient coal, and its fossil plants, with the great peat-mosses of the present day, states, in a memoir published in 1838, that he continues to adhere to the opinions originally advanced by Werner and De Luc, that the vegetation entombed in the carboniferous strata, chiefly grew in the localities where the coal is now found.* Whether Mr. Brongniart, however, endeavors to conform this view to all the phenomena of the coal-measures, under any general theory of their origin, I am not informed, not having seen his memoir.

Mr. Hawkshaw, in a communication to the Geological Society of London, in 1839, describes the remarkable phenomenon of five fossil trees, exposed in a cutting on the Manchester and Bolton railway, standing erect in relation to a bed of coal, eight or ten

* LYELL'S Elements, Vol. II, p. 135, Boston edition.

inches thick, and in the same place with their roots. The largest of these was five feet in diameter, at the base, and eleven feet high. He conceives it probable, that they grew where they occur.* In a subsequent paper, read February 26, 1840, Mr. Hawkshaw, after mentioning the discovery of another fossil tree, standing on the same coal-seam, makes this observation : " If the coal be considered as the debris of a forest, it is difficult to account for not finding more trunks of trees than have been discovered in our coal-basins, and it is only, perhaps, by allowing the original of our coal-seams to have been a combination of vegetable matter, analogous to peat, that the difficulty can be solved."†

After Mr. Hawkshaw's first communication, Mr. Beaumont, in a paper read to the same Society, November 6th, 1839, upon the subject of the same trees, states several objections to the drift theory of coal, and conceives, that the vegetation grew where it is found. Upon comparing these objections with my own, as given in the foregoing pages, I find that they all rest upon a different class of facts, and are wholly distinct in their bearings. Mr. Beaumont states, that the vegetation which formed the coal grew on swampy islands, that it consisted of *ferns*, *calamites*, *coniferous trees*, &c., which operated, through their decay and regeneration, to form peat bogs; and that the islands, by subsiding, were covered with drifted sand, clay, and shells, till they again became dry land, and supported another vegetation; and this process, he supposes, was repeated as often as there are coal-seams.‡

Dr. Buckland, in commenting on this hypothesis, observes, that, "in denying altogether the presence of drifted plants, the opinion of the author seems erroneous; universal negative propositions are in all cases dangerous, and more especially so in geology. That some of the trees, which are found erect in the coal-formation, have not been drifted, is, I think, established on sufficient evidence; but there is equal evidence to show, that other trees and leaves innumerable, which pervade the strata that

* Hawkshaw, in Proceedings Geological Society, London, No. 64.

† Hawkshaw, in Proceedings Geological Society, London, No. 69.

‡ Beaumont, in Proceedings of Geological Society, London, No 65.

alternate with the coal, have been removed by water to considerable distances, from the spots on which they grew. Proofs are daily increasing in favor of both opinions, namely, that some of the vegetables which form our beds of coal grew on the identical banks of sand, and silt, and mud, which, being now indurated to stone and shale, form the strata that accompany the coal; whilst other portions of these plants have been drifted to various distances from the swamps, savannahs, and forests, that gave them birth; particularly those, that are dispersed through the sandstones, or mixed with fishes in the shale beds.* In these views of Dr. Buckland, Mr. Lyell would seem to concur, as, in quoting the above passage, in his Elements, he says, that "it can be no longer doubted, that both these opinions are true, if we confine our attention to particular places."

Another paper, on the same subject of the fossil trees, found on the Manchester and Bolton railway, was read contemporaneously with the last communication of Mr. Hawkshaw. The author, Mr. Bowman, is of opinion, "that the theory of the subsidence of the land during the carboniferous era, receives much support from the phenomena presented by these fossil trees." He does not deny, that plants may have been carried into the water from neighboring lands; but he conceives it difficult to understand whence the vast masses of vegetables, necessary to form thick seams of coal, could have been derived, if drifted, and how they could have been sunk to the bottom without being intermixed with the earthy sediment, which was slowly deposited upon them. Another difficulty of the drift theory, he says, "is the uniformity of the distribution of the vegetable matter throughout such great areas as those occupied by the seams of coal." I have myself shown, that this uniformity extends even to the subordinate divisions of each seam. Mr. Bowman believes, that the coal has been formed from plants, which grew on the areas now occupied by the seams; that each successive race of vegetation was gradually submerged beneath the level of the water, and covered up by sediment, which accumulated till it formed another

* Anniversary Address to Geological Society, 1841.

dry surface for the growth of another series of *trees* and plants, and that the submergences and accumulations took place as many times as there are seams of coal.*

In reviewing the above facts and opinions, Dr. Buckland conceives, that a luxuriant growth of marsh plants, as *Calamites*, *Lepidodendra*, *Sigillaria*, &c., may have formed a superstratum of coal, resting on a substratum of the same, composed exclusively of remains of *Stigmariæ;* and in accounting for the marine and freshwater strata alternating with the coal-beds, he appeals to the intermitting and alternate processes of subsidence, drift, and vegetable growth.†

The above summary of the recent researches and speculations of geologists, conveys, I believe, a correct view of the state of opinion at the present time, in relation to the interesting problem of the origin of the coal strata. I may now venture to advance my own explanation of the phenomena, and to indicate wherein I differ from the able authors I have cited. The several hypotheses proposed, do not attempt to account for some of the most remarkable relationships among the strata, such as the extraordinary frequency, beneath the coal-beds, of the Stigmaria clay, the very general occurrence of laminated slates immediately above the seams, and the singular contrast which these underlying and overlying rocks present, in the variety and condition of the imbedded vegetable remains. Nor do they explain satisfactorily why the coal itself contains so few traces of the forest trees of the period, either in a prostrate or erect position; while their broken stems are mingled with the fragmentary parts of the Stigmaria, in more or less abundance, in all the coarser rocks. Perhaps the following hypothesis will account for the phenomena.

Let us imagine the areas now covered with the coal-formation, to have possessed a physical geography, in which the principal feature was the existence of extensive flats, bordering a continent, and forming the shores of an ocean, or some vast bay, outside of which was a wide expanse of shallow but open sea. Let us now

* BOWMAN in Proceedings Geological Society, London, No. 69.

† Anniversary Address to Geological Society, 1841.

suppose, that the whole period of the coal-measures was characterized by a *general* slow subsidence of these coasts, on which we conceive that the vegetation of the coal grew; — that this vertical depression, was, however, interrupted by pauses and gradual upward movements of less frequency and duration, and that these nearly statical conditions of the land, alternated with great paroxysmal displacements of the level, caused by those mighty pulsations of the crust which we call earthquakes. Let us further conceive, that during the periods of gentle depression, or almost absolute rest, the low coast was fringed by great marshy tracts or peat-bogs, derived from and supporting a luxuriant growth of *Stigmariæ*, and that along the land-ward margin, and in the drier places of these extensive sea morasses, grew the *Coniferæ*, *Tree-Ferns*, *Lycopodiaceæ*, and other arborescent plants, whose remains are so profusely scattered throughout the coarser strata between the coal-seams. In this condition of things, the constant decomposition and growth of the meadows of *Stigmariæ*, would produce a very uniform, extended stratum of pulpy but minutely laminated pure peat. This would receive occasional contributions from the sheddings by the dispersed trees of their leaves, fronds, and smaller portions, which, being driven by winds, or floated on the high tides, would lodge among the Stigmariæ in the marshes, and slightly augment the deposit. These leaves and fronds, covered over more or less rapidly by the growing *Stigmariæ*, or varying in their tendency to decay, according to the abundance or deficiency of their juices, would, when thus inclosed, pass at once either to the pulpy state, and ultimately form coal, or, by the more rapid extrication of their volatile portions, remain as mineral charcoal, and preserve their vegetable fibrous structure. In both of these conditions of coal and charcoal, we often find the smaller parts of plants retaining their organized forms among the laminæ of the purest coal-seams. Upon this view of a gradual accumulation from the *Stigmariæ*, assisted by the deciduous parts of the trees, it is altogether unnecessary to suppose, that any portions, even the upper layers of the coal-beds, derived their vegetable matter from the stems of the trees themselves. Thus the absence of trunks and roots from the coal is reconciled with the occasional occurrence of their fronds and lighter extremities. Upon no other hypothesis respecting the physical condition of the region which produced the coal vegetation than that here imagined, can I explain the singular infrequency of fossil trunks standing on or in the coal, or account for their occasional occurrence, as in the instances described by Hawkshaw and Bowman. No other supposition seems to furnish a cause for the absence of all traces in the coal itself, of the larger parts of arborescent plants, and for their equally remarkable abundance in a broken and dispersed state in the overlying strata.

Assuming such to have been the condition of the surface during the tranquil periods of the accumulation of each coal-bed, we may conceive the other strata to have been produced in the following manner. Let us suppose an earthquake, possessing the characteristic undulatory movement of the crust, in which I believe all earthquakes essentially to consist, suddenly to have disturbed the level of the wide peat-morasses and adjoining flat tracts of forest on the one side, and shallow sea on the other. The ocean, as usual in earthquakes, would drain off its waters for a moment from the great Stigmaria marsh, and from all the swampy forests which skirted it, and, by its recession, stir up the muddy soil, and drift away the fronds, twigs, and smaller plants, and spread these, and the mud, broadly over the surface of the bog. In this way may have been formed the laminated slates, so full of fragmentary leaves and twigs, which generally compose the immediate covering of the coal-beds. Presently, however, the sea would roll in with impetuous force, and, reaching the fast land, prostrate every thing before it. Almost the entire forest would be uprooted and borne off on its tremendous surf. Spreading far inland, compared with its accustomed shore, it would wash up the soil and abrade whatever fragmentary materials lay in its path, and, loaded with these, it would then rush out again, with irresistible violence, towards its deeper bed, strewing the products of the land in a coarse promiscuous stratum, imbedding the fragments of the broken and disordered trees. Alternately swelling and retiring, with a suddenness and energy far surpassing that of any tide, and maintained probably in this state of tempestuous oscillation, by fresh heavings of the crust, the waters would go on spreading a succession of coarser or finer strata, and entombing at each inundation a new portion of the floating forest. Upon the dying away of the earthquake undulations, the sea, once more restored to tranquillity, would hold in suspension at last, only the most finely subdivided sedimentary matter, and the most buoyant of the uptorn vegetation, that is to say, the argillaceous particles of the fire-clay, and the naturally floating hollow stems of the *Stigmariæ*. These would at last precipitate themselves together, by a slow subsidence, and form a uniform deposit, exhibiting but few traces of any active horizontal currents, such as would arise from a drifting into the sea from rivers. The chief portion of the coarser fire-clay would settle first, and then the more impalpable particles, in company with the stems and leaves of the *Stigmariæ*. Thus we may account for the constant reproduction of the peculiar soil of the coal-seams, and for the preservation, particularly in its upper layers, of the Stigmaria plant; the simple consequence of the final subsidence of these materials, being the production of the necessary substratum of another coal-marsh. The marine savannahs becoming again clothed with their spongy matting of *Stigmariæ*, and fringed on the side towards the land with wet fórests of arborescent Ferns, all the essential conditions and changes that constituted this wonderful cycle in the statical and dynamic processes belonging to each seam of coal, and the beds enclosing it, would be completed, and ready to be once more renewed. In the hypothesis now proposed, the great relative buoyancy of the *Stigmariæ* is considered, and we have the testimony of Dr. Buckland and others, to show that it was a plant admirably fitted by its structure, to float upon the surface of the water.

Though the train of actions here imagined enables us to reconcile the indications afforded by the coal-beds, of periods of prolonged tranquillity, with the evidences of violent aqueous currents, as shown in the composition of the coarser mechanical rocks; yet a complete theory of the coal-formation calls for the introduction of other considerations connected with the existence and positions of strata, derived from chemical and organic agencies, as the limestones, cherts, and beds of carbonate of iron. The analysis already given of our Appalachian coal-measures, will be seen to imply a slow general subsidence, alternating with occasional and less prolonged movements of elevation; these gentle changes of level, interrupted by sudden or paroxysmal heavings of the crust. Mr. Beaumont was the first, I believe, to suggest a subsidence of the land during the progress of the coal-formation; he supposes the coal-beds to be the result of a "luxuriant vegetation, covering swampy islands, which, by the settling down of the disturbed crust of the earth, were covered over with drifted sand, clay, &c." Subsequently Mr. Lyell, in the last edition of his Elements of Geology, proposes a somewhat similar view. He says, "If the superposition on a great scale of purely marine strata to others containing coal and fresh-water shells, leads us to infer that large areas, once constituting estuaries, deltas, and marshes, sank down and became sea during the carboniferous period, so are there reasons for concluding, that in many cases the depression of the ground took place gradually, and that in consequence of the deposition of sediment, the same space was again and again converted into land and laid under water." In another passage he suggests, that "If we appreciate the full strength of the evidence in favor of continued subsidence in the coal-field of South Wales, we shall be the less surprised to learn that the vertical depth of the superimposed strata is enormous, amounting in some places to no less than twelve thousand feet."* Though a vast preponderance of subsidence over elevation is plainly indicated in the prodigious thickness of the coal-measures, each particular coal-seam in which was produced successively at the surface, I cannot conceive that either an alternation of periods of subsidence and repose, or an uninterrupted prolonged depression, will explain the phenomena of the Appalachian coal rocks, as they have been here described. A general subsidence throughout the coal period, of all the great area now occupied by the Appalachian basins, is proved independently of the above evidence derived from the nature of the coal-beds, by the interesting fact, that the lower seams of Ohio and western Pennsylvania, have

* Lyell's Elements, Bost. edit., Vol. II., pp. 128 and 134.

their eastern limit more than one hundred and fifty miles to the west of the general eastern boundary of the upper ones; and, as we ascend in the formation, the beds extend successively more and more to the east, or in the direction of the ancient land. But considering the many striking instances which I have recorded, of the close approach or actual contact of certain beds of coal and oceanic limestone, we cannot resist the conclusion, that the gradual downward movement was frequently interrupted by a slow upward one. In all the instances that I have cited, where the limestone stratum immediately underlies a coal-seam, it is obvious that an upward movement of the land must have taken place, so gradually as to be unattended by any sensible commotion of the waters. A considerable and sudden lifting of the bed of the sea, would infallibly have caused the production of violent currents, competent to spread over the quiet precipitate of limestone, one or more coarse arenaceous or argillo-arenaceous strata. That the intervals of repose, indicated by the limestones, were, like those of the beds of coal, sometimes suddenly terminated by earthquake disturbances, strêwing over the marine sediments the materials of the land, is manifest from the phenomena, though it is not less clear, that the cessation of the periods of relative tranquillity, marked by very gradual subsidence, must, in all cases, where the coal-beds are overlaid directly by marine limestones, have been effected by simply a more rapid process of depression. Every superimposed limestone, without an intervening roof-slate, or sandstone, to separate it from the coal, affords, I conceive, a conclusive proof of this increased rate of submergence. Perhaps it will be objected, that a merely accelerated subsidence, such as I have here supposed, if taken in conjunction with the hypothesis of a drifting of the land materials by rivers, will satisfactorily explain all the facts which I have ascribed to the turbulent movement of the sea against the land during earthquakes. But though it is highly probable, from the phenomena of nearly every extensive coal-field, that rivers did carry into the parts of the ocean and its estuaries, now drained and occupied by the coal strata, a considerable quantity of argillaceous deltal deposits, yet it is difficult to imagine how any moderately rapid subsidence, if unaccompanied by some *paroxysmal* movement, could create a current energetic enough to uproot and float away nearly the whole of those vast forests, which evidently grew close to the site of each seam of coal, and to snap off to the stumps, even the most colossal trees. Nor is it easy to explain, why such a quiet submersion of the swampy forests did not result in the preservation of the trees in their original erect posture, by the drifting around them of the supposed river sediments. It is fair to infer, that so long a line of coast as we conceive bordered the Appalachian ocean, if we may judge from the great longitudinal extent of some of our coal-seams, was not destitute of rivers, and we are therefore constrained to admit that some amount of sedimentary matter must have entered the sea in that manner; but at the same time, we have only to notice the striking deficiency of earthy matter in the numerous coal-beds, and in many of the strata of limestone, to be persuaded, that the amount of material contributed to the coal-measures by fluviatile transport, was relatively inconsiderable. It may be fairly questioned, whether any sensible proportion of river silt, could spread itself to the distance of one hundred and fifty or two hundred miles seawards, over the great coal morasses of such a coast, and yet we must suppose this, if we deny the above paroxysmal theory.

That the geological and geographical changes known to have been caused in modern times by earthquakes, entitle us to speculate upon their agency in suddenly shifting the level of the low tracts once occupied by the marshes and swamps of the coal-seams, must, I think, be conceded. Few geologists will deny the probability of frequent changes, in the carboniferous period, analogous to that which took place in the great plain at the mouth of the Indus, in the year 1819. It is mentioned in Mr. Lyell's Elements, that "extensive flats bordering the Indus, sank down, and for many years after, vessels were forced through the boughs of the tamarisk trees, still standing erect."*

Should the foregoing theory, based on the complicated statical and dynamic phenomena of the Appalachian coal strata, be cor-

* Lyell's Elements, Vol. II, p. 136.

rect, then have we, in every stratum of the series, not merely a new picture of the physical geography of the region, but a clear legible record of the very changes, gradual or tempestuous, of which each in its turn was the result. We unclasp, as it were, a whole volume of hydrographic charts, displaying, for a vast succession of epochs, the ever-changing relations of the land and waters. A wide tract of ancient coast is at one time occupied by the ocean, at another by an immense plain, filled with green marshes and swamps, and at another by dry land, clothed with an impenetrable forest. But we behold more than merely these several conditions of the surface; we perceive the very transitions themselves which revolutionized the geography; we discern the ocean in the very act of encroaching on the land, forming extensive marshes, where before the whole was solid shore; we actually trace it in its gradual retreat, exposing its own marine sediments to form a fertile soil for vast savannahs of the *Stigmariæ*, and again we see the entire region embracing the dry land, the marshes, and the sea, heaving and undulating in the billows of the irresistible earthquake, the ocean and the land contending for mastery in the tremendous conflict.

If the Appalachian coal strata, whose history I have here endeavoured to interpret, exhibit truly the above-imagined conditions and events, we may consider the entire formation as constituting a stupendous tide-gage, registering the lengthened ebbings and flowings of that ancient sea, and the stormy agitations of its eternally oscillating waters, as the epoch of its last, greatest movement, and final drainage, drew near.

Of the Gradation in the Proportion of Volatile Matter in the Coal of the Appalachian Basins.

There prevails a very interesting law of gradation, in the quantity of volatile matter belonging to the coal, as we cross the Appalachian basins from the southeast towards the northwest. The extraordinary extent of area over which this law obtains, and its intimate connection with corresponding gradations in the structural phenomena of the region, the description and theory of which have been given by my brother and myself in another communication, seem to claim for it a place in the present general account of our coal-measures. The gradation may be thus briefly described. Crossing the Appalachian coal-fields, northwestward from the great valley, to the middle of the main or western trough, by any section between the northeastern termination of the formation in Pennsylvania, and the latitude of Tennessee, we find, as the result of multiplied chemical analyses, a progressive increase in the proportion of the volatile matter, passing from a nearly total deficiency of it, in the dryest anthracites, to an ample abundance in the richest caking coals. The existence of this singular law of transition was first ascertained by me in 1837, in which year I made mention of it in some public lectures. It was communicated to the Association of American Geologists, at their first Annual Meeting, in the spring of 1840; but I did not publish it in print until the following winter, when it was briefly alluded to in my fifth Annual Report on Pennsylvania. Evidence of the existence of such a gradation in the coals of western Virginia, will be found in the Annual Reports of the Geological Survey of that State, for the years 1839 and 1840. These historical references are here introduced, because the determination of the general fact was the result of many laborious analyses of our coals, made by my brother and myself, and because attempts have been made by others, to establish a claim to the discovery. The lists of analyses contained in the Reports of the Surveys of Pennsylvania and Virginia, and similar data not yet published, show the following as the general proportion of the bituminous matter, in the different belts of the formation, as we cross the region from southeast to northwest.

First. In the most southeasterly chain of basins, the coal is, for the most part, a genuine anthracite, containing sometimes, however, a small per centage of bitumen, and always a little gaseous matter, chiefly hydrogen. The quantity of the volatile matter varies according to geological locality, from about six to twelve or fourteen per cent. This first belt of basins embraces all the anthracite coal-fields of Pennsylvania, the slightly bituminous ones of Broad Top on the Juniata, of Sleepy creek, of the Little North mountain, of Catawba creek, Tom's creek, Strouble's run, and Brushy ridge, in Virginia. The coal of the Little North mountain, is, however, a true anthracite. All of these coal-fields, and insulated patches of the formation, belong to the most disturbed portions of the Appalachian chain, and they are associated with some of the boldest flexures and greatest dislocations of the whole region. The first or southeastern anthracite basin of Pennsylvania, presents innumerable sharp flexures and close plications, with inversion, of the strata.

Secondly. In the next well-defined range of basins further towards the northwest, that namely of the Allegheny mountain, and the general escarpment of which it is a part, the proportion of volatile matter varies usually from sixteen to twenty-two per cent.; but is generally about eighteen or twenty per cent. This belt includes all the coal-fields, situated immediately to the northwest of the Allegheny mountain, in Pennsylvania; also, the Potomac basin, in nearly the same line, and the coal-fields of the Little Sewell, and the eastern side of the Big Sewell mountain, in Virginia. The position of this belt of the coal-measures is somewhat west of the region of steep flexures of the strata, and beyond all the considerable dislocations; while it embraces a few very extensive, regular, and nearly symmetrical anticlinal axes of the flatter form, distinctive of their intermediate position between the east and west.

Thirdly. The great Appalachian basin, with its subordinate troughs, forming the wide coal-field watered by the Ohio river and its tributaries, embraces a series of coal-beds, which are all distinguished by a still larger amount of volatile matter. In crossing the breadth of this wide coal-field, we find a very material alteration in the character and composition of the coal. Along its eastern side, or near the last considerable axis of the Appalachian chain, the amount of volatile matter is commonly from thirty to thirty-five per cent. Westward of this line, on the Monongahela river, both in Pennsylvania and Virginia, the proportion approaches to forty per cent., while still further in the same direction, or near the Ohio river, it ranges from forty to even fifty per cent., according to local circumstances. In this most western or main coal-field, the flexures of the strata are extremely gentle, and comparatively wide apart; but, even here, we observe a beautiful progression in the amount of the bitumen, as we recede from the very low axes which traverse the southeastern side of the great plain. What renders the foregoing comparison of the several ranges of the coal-formation particularly exact and satisfactory is, the circumstance, that, in more than one instance, we are enabled to trace the very same coal-seam, through its various degrees of bituminization, from an almost true anthracite, to a form in which it possesses a full proportion of volatile matter. Thus the great Pittsburg bed, to take it as an example, contains on the Potomac, in some localities, as little as 15.5 per cent., but near the eastern margin of the great western basin, as at Blairsville, and again in Virginia, it has about thirty-one per cent, and towards the middle of the main basin at Pittsburg and on the Kenawha, as much as from forty to forty-three per cent.

The cause of the different degrees of de-bituminization of the coals, in different parts of their range, I am disposed to attribute to the prodigious quantity of intensely heated steam and gaseous matter, emitted through the crust of the earth, by the almost infinite number of cracks and crevices, which must have been produced during the undulation and permanent bending of the strata. All the phenomena of modern earthquakes and volcanos, warrant us in supposing that the elevation of our coal rocks, if effected in the manner I have imagined, must have been accompanied by the escape of an immense amount of hot vapors, the chemical and thermal agency of which cannot be overlooked, upon any hypothesis of the rending and uplifting of great mountain tracts. It is easy to conceive, that the coal, throughout all the eastern basins, if thus effectually steamed, and raised in temperature in every part of its mass, would discharge a greater or less proportion of its bitumen and other volatile constituents, as the strata were more or less frequently and violently undulated by earthquake action. It is also obvious, that the more western beds, remoter from the region of active movements, less crushed and fissured, and presenting a greater resistance to permeation by the subterranean vapors, would, in virtue of their mere geographical position in the chain, be much less extensively de-bituminized. The striking fact that we nowhere, not even in the most dislocated and disturbed districts of the anthracite coal-field, find any traces of true igneous rocks, that, by their contiguity to the coal, could have caused the loss of its bitumen, is a circumstance in their geology, which goes far to confirm the truth of the hypothesis. Precisely in proportion as the flexures of the strata diminish in our progress westward, does the quantity of the bitumen in the coal augment; but it is difficult to conceive how any such law of gradation could have been the result of a temperature transmitted by conduction from the general lava mass beneath the crust, for that would imply a corresponding increasing gradation in the thickness of the crust, advancing westward under the coal-fields, whereas such an inference is in direct conflict with the fact of the general diminution westward of the Appalachian rocks, besides being inconsistent with all correct geothermal considerations, which forbid our imagining so unequal a conduction to the surface, of the earth's interior temperature.

On the Physical Structure of the Appalachian Chain, as exemplifying the Laws which have regulated the Elevation of great Mountain Chains, generally.

By W. B. Rogers, *Professor of Natural Philosophy in the University of Virginia, and* H. D. Rogers, *Professor of Geology in the University of Pennsylvania.*

Having, in the prosecution of the State Geological Surveys of New Jersey, Pensylvania, and Virginia, arrived at certain general facts in the structure of the Appalachian chain, involving some new considerations in Geological Dynamics, we propose, in the present memoir, to offer a description and theory of the phenomena. As similar structural features would appear, upon comparison, to prevail in many of the disturbed regions of other countries, and among strata of all geological dates, an exposition of their laws cannot be uninteresting at this time, when every question connected with the elevation of the earth's crust, is receiving so generally the attention of geologists.

To render our details intelligible in the absence of a geological map, we must first enter upon a brief geographical description of the extensive zone of country where these structural conditions exist. Such a preliminary sketch is the more essential, since, in no region yet described, does the topography or physical relief of the surface, afford as accurate an index to the positions and relations of the strata, and to the movements by which they have been uplifted.

The Appalachian chain rises in the form of a broad belt of mountain ridges east of the St. Lawrence, in the northern part of New England, and, taking a southwesterly course, terminates in Alabama. Its total length is about one thousand three hundred miles, and its greatest breadth about one hundred, if we exclude from this description the high insulated tracts of the White Mountains in New Hampshire, and that west of Lake Champlain, in New York. From the northern border of Vermont, the main chain gradually expands in width to the region of the Juniata and Potomac rivers, beyond which, in its progress to the southwest, it slowly and steadily contracts to its termination. While the great chains of many countries contain a principal central mountain axis, to which all the minor ranges more or less conform, this system consists of a broad zone of almost innumerable parallel ridges of nearly equal average height. These seldom reach an elevation of four thousand feet above the sea; nor, if we except the great eastern range, the Blue ridge, do they often rise more than two thousand feet from the level of the adjoining valleys, the more usual height being from eight hundred to one thousand five hundred feet. The general plain, supporting this broad mountain belt, gradually declines in level from the head waters of the Holston and Clinch rivers, in Virginia, towards both extremities.

The characteristic features of the Appalachian ridges, are their great length, narrowness, and steepness; the evenness of their summits, and their remarkable parallelism. Many of them are almost perfectly straight for a distance of more than fifty miles; and this feature, combined with their steep slopes, and sharp, level summits, gives them the appearance, seen in perspective, of so many colossal entrenchments. Some groups of them are curved, but the outlines of all are marked by soft transitions, and an astonishing degree of regularity. It is rather the number and great length of the ridges, and the magnitude of the belt which they constitute, than their individual grandeur or height, that places this chain among the great mountain systems of the globe. From the latitude of the Mohawk river, in New York, to the northern boundary of Alabama, the chain in general consists of four parallel belts, the separate features of which it is convenient we should define.

1. The first or southeastern subdivision is the relatively narrow, undulating mountain range, which, in Vermont, is called the Green Mountains, in New York the Highlands, in Pennsylvania the South Mountain, in Virginia the Blue Ridge, and in North Carolina and Tennessee the Smoky or Unaka mountains. This is rather a zone of closely united ridges, than one great mountain axis, though the latter is somewhat its character in Virginia, North Carolina, and Tennessee, in which States it has its greatest breadth and elevation. The average width of this belt may be stated at about fifteen miles, and its height, which is more variable than that of any other portion of the general chain, undulates between about one thousand and five thousand feet above the sea.

The rocks of this tract consist for the most part of the older metamorphic strata, including gneiss, and micaceous, chloritic, talcose, and argillaceous schists, together with masses referable to the earliest Appalachian formations, sometimes in a highly altered condition. Throughout nearly the whole distance, from Tennessee to the Susquehanna, these latter rocks occupy the northwestern slope of the main ridge, and form the ranges of hills, sometimes of great height, flanking it on the northwest; while in Pennsylvania, New Jersey, Massachusetts, and Vermont, besides presenting themselves in this position, they form narrow belts and ridges among the older metamorphic strata towards the southeast.

Innumerable dykes and veins of all dimensions, and consisting of a vast variety of igneous materials, penetrate this belt, disturbing and altering its strata in a remarkable degree.

2. Immediately to the northwest of this mountain range is a broad valley, which constitutes by itself a well-defined belt throughout the entire length of the chain, displaying a remarkable constancy in its structure and physical features. This, which we shall call the *Great Appalachian Valley*, ranges from Vermont to Alabama, under various local names, being known in New York as the Valley of Lake Champlain and the Hudson river, in Pennsylvania as the Kittatinny or Cumberland Valley, and further south successively, as the Great Valley of Virginia and the Valley of East Tennessee. Its average breadth throughout, is about fifteen miles, forming an unbroken and nearly level plain, except in Virginia and eastern Tennessee, where several long insulated ridges, rising in it, separate it for a greater or less distance into two or more narrow parallel valleys. The stratification every where in this great belt is exceedingly disturbed, the rocks consisting principally of the three lower Appalachian formations, being, only in a very few instances, invaded, however, by igneous dykes.

3. Beyond the *Great Appalachian Valley* on the northwest, is a wide belt of long, narrow, parallel ridges and included valleys, spreading northwestward to the foot of the great plateau of the Allegheny and Cumberland mountains. This, which we propose to call the *Middle Mountain-belt*, has a breadth varying from thirty to sixty miles, its greatest expansion being in the curving region of the Juniata in Pennsylvania. It embraces all the Appalachian formations to the coal inclusive.

4. The fourth or most northwestern of the belts into which we have divided the Appalachian chain, commences with the southeastern escarpment of the great table-land of the Catskill, Allegheny, and Cumberland mountains, and spreads northwestward with a gentle declivity, as far as the limits of the last feeble axes of elevation. The average breadth of this belt, measured from the southeastern escarpment of the plateau, to the plain which

bounds it on the northwest, may be stated at about thirty-five miles. This portion of the chain embraces all the upper Appalachian formations, including the whole of the carboniferous group.

Following the course of this great mountain belt from Canada to Alabama, it will be seen to consist of a series of nine straight and curved portions in alternate succession, distinguished from one another by important topographical features, as well as by peculiarities of geological structure, *and forming nine distinct divisions.*

1. Of these the first, or *Hudson River Division*, extends from Canada to New Jersey, following the general course of the Hudson as far as the Highlands in New York, and comprising not only a large area in the eastern and northern parts of that State, but a considerable tract in western Vermont and Massachusetts. Along the great valley, from the northern part of Vermont to the passage of the Hudson through the Highlands, the strike of the rocks, and the direction of the axes, is about north fifteen degrees east, and south fifteen degrees west.

2. From where the Hudson crosses the Highlands, to the Lehigh river in Pennsylvania, the whole chain *bends* gradually westward, taking a long and regular sweep concave to the northwest. This portion of the chain we propose to call the *Delaware Division.*

3. The next is a nearly *straight* part of the chain; extending from the Lehigh river to Cumberland county, in Pennsylvania, and may very properly be named the *Susquehanna Division.* Throughout this tract the strike is from east-northeast to west-southwest.

4. To the southwest of the foregoing is the highly interesting *curving* portion of the chain, which we shall call the *Juniata Division.* This diversified region extends from about twenty miles west of the Susquehanna, to nearly the same distance north of the State line of Maryland, and is characterized by a regular and very decided curvature, convex towards the northwest. The formations, in ranging between the above limits, change their strike from south seventy degrees west, to south thirty degrees

west, undergoing thus a deviation in their course of forty degrees.

5. The next division is one of *straight* or nearly straight axes. It extends from the southern counties of Pennsylvania, to the southern side of Augusta, Pendleton, and Randolph counties, in Virginia, with a strike of the rocks about north thirty east, or south thirty west. This we shall call the *Potomac Division.*

6. The portion of the chain next succeeding, has a decided *sweep*, concave towards the northwest. It extends from the southern limit of the previous one to the New river, and, being extensively watered by the tributaries of the James river, may be designated as the *James River Division.* The belt here referred to differs from the three last, in possessing a less symmetrical topography, and a less regular strike in its strata. Its axes are also shorter and less perfectly parallel, and the whole tract is considerably narrower, the width, from the Blue ridge northwestward, across which the undulations of the strata extend, not exceeding sixty miles.

7. The division next in order, which is one of *straight* axes, commences northeast of the New river, in Virginia, and extends nearly to the mouth of the Holston, in Tennessee. Being watered for a great distance longitudinally, by the latter stream, it may be appropriately named the *Holston Division.* Both in the style of the topography, and the phenomena connected with the dipping of the strata, this is one of the most remarkable parts of the chain. The direction of its axes and faults is about north sixty-seven east, and south sixty-seven west. Its length exceeds two hundred miles, but its breadth is somewhat inferior to that of any of the previous divisions, not amounting to more than fifty-five miles from the Blue ridge to the most northwestern axis.

8. At the southern termination of the belt above described, near the mouth of the Holston, commences the next division of the chain. This has a *curving* outline, concave towards the northwest, the direction of the axes and the strike of all the strata, gradually changing from south sixty-seven west, to south thirty-five west, making a deflection of thirty-two degrees. Traversing the central parts of eastern Tennessee, and including in it the

well known town of Knoxville, it may be entitled the *Knoxville division*. In this, as in the division last mentioned, the whole disturbed space is comparatively narrow.

9. The last or ninth division of the chain extends from the southern termination of the Knoxville section, near the mouth of the Clinch river, to the neighborhood of Tuscaloosa, in the centre of Alabama. This we propose to call the *Alabama Division*. Unlike the district just preceding, it exhibits almost perfect *straightness* in its axes; the strike, which is about south thirty-five west, continuing unchanged until the strata disappear beneath the horizontal formations of the cretaceous and tertiary systems of middle Alabama.

Predominance of Southeastern Dips.

While the general direction of the Appalachian chain is northeast and southwest, there is a remarkable predominance of southeastern dips throughout its entire length from Canada to Alabama. This is particularly the case along the southeastern or most disturbed side of the belt, where it is strikingly exhibited in the great valley, and in the extensive mountain ridges that bound it on the southeast. But, as we proceed towards the northwest, or from the region of greatest disturbance, the opposite, or northwest dips, which previously were of rare occurrence, and always very steep, become progressively more numerous, and, as a general rule, more gentle.

Of the prevalence of this interesting general law throughout all the part of the chain extending from western Massachusetts into eastern Tennessee, we have convinced ourselves by a personal examination of the entire tract, during the last six years, and have partially announced it in various passages of our Reports on the Geology of New Jersey, Pennsylvania, and Virginia. We learn from Dr. Charles T. Jackson, and other sources, that the prevailing southeastern dip extends to western Vermont, and the valley of Lake Champlain.

Upon the correct interpretation of this singular feature depends, we conceive, the clear elucidation of whatever relates to the dynamical actions which the region has experienced, to the strata-graphical arrangement of the rocks, and, as immediately connected with this, to the distribution of their organic remains. The object of the present paper is, to exhibit those general laws of structure, of which the feature in question is but a simple and immediate consequence, and to develope what we have for several years past regarded as the true theory of the flexure and elevation of the Appalachian rocks.

History of the previous Explanations of the general southeasterly Dip in the Great Appalachian Valley.

The first published attempt at explaining the seeming anomaly of a general southeasterly dip across the great valley, was made by Prof. Hitchcock, in the first edition of his Report of the Geology of Massachusetts, in 1833. This explanation, which was confined to the phenomena of western Massachusetts, supposes a series of unconformable deposits all dipping to the east, at different angles; but Prof. Hitchcock does not suggest the idea of either an inversion or a folding of the rocks.

At an early period in the geological surveys of New Jersey, Pennsylvania, and Virginia, we were struck with the great prevalence of the southeasterly dip of the strata throughout the portions of the Appalachian chain traversing those States, and recognized its dependence on the oblique or inverted folding of the strata. This will appear from the descriptions we have given of the phenomena, in our Annual Reports for 1837 to 1839. The important general law of a greater steepness of the dip on the northwestern than the southeastern sides of the anticlinal axes, became known to us at the same stage of our inquiries, and was first announced in the Final Report on the Geology of New Jersey, written in 1839, and published early in the spring of 1840.

Our solution of this question of the southeasterly dips, which we have long supposed to constitute the only key to the structure of our great mountain chain, was communicated in conversation to Professors Hitchcock and Emmons, at the first Annual Meeting of the Association of American Geologists, in the spring of 1840.

The next notice in the order of time of this structure is, that given by Prof. Hitchcock in his Elementary Geology, published in August, 1840. In this work, Prof. H. refers to our published observations respecting the extensive inversion of the strata in Pennsylvania and Virginia, and proposes to explain the prevailing southeasterly dip in western Massachusetts, and the Hudson river district, by the hypothesis of a simple but vast inversion of all the rocks extending entirely across the region in question. This explanation, accompanied by a short section through the Hoosic and Taconic mountains, is given as an instance of *inversion*, and not of the *folding* of strata, the latter subject being discussed separately on another page.

At a meeting of the American Philosophical Society, on the first of January, 1841, one of us communicated the results of some observations upon the geological structure of Berkshire, Mass., and the neighboring parts of New York, which we had made during the month of August previous, and gave an outline orally of our theory, explanatory of the phenomena. After adverting to the statements of previous writers, that all the strata between the Hoosic mountain and the Hudson river, lie in an inverted order, drawings were exhibited, proving the existence of numerous closely-folded anticlinal and synclinal axes; and the inference was drawn, that the inverted dip of the rocks is the result of a folding of the beds at short intervals, and not of one general turning over of the whole series, as suggested by Prof. Hitchcock. Subterranean igneous action was referred to as having caused this compression and folding of the rocks, and its energy was shown to have been greatest along the Berkshire valley, and the ridges lying to the east. To the same agency was attributed the crystalline condition of the Berkshire marble, and of the associated schists and semi-vitrified quartz rock, the first being regarded as merely the blue limestone of the Hudson valley, extensively altered, and the last a highly altered form of the white sandstone at the base of the Appalachian formations.*

In the following April, Prof. Hitchcock, in his very able address

* See Proceedings of American Philosophical Society for January, 1841.

to the Geological Association, speaking of the remarkable apparent inversion of the dip, along the western side of New England, and through the Appalachian chain, no longer ascribes the phenomena simply to a toss over of the strata, but to a succession of folded axes, causing a high or more frequently an inverted dip on the western side. In another part he states, that although he does "not fully adopt, he cannot but look with a favorable bias upon this solution of the problem." In explanation of the manner in which the strata acquired this folded structure, he supposes that while yet in a plastic state, and but slightly elevated, they were acted upon by a force exerted in opposite directions, from near the Hudson and Connecticut rivers; and observes, that this force, "if powerful enough, might cause them to be folded up into several ridges, and if more powerful along the western than the eastern side, they might fall over so as to take an inverted dip, without producing any remarkable dislocation."

In the second edition of his Elementary Geology, published in August, 1841, Prof. Hitchcock, in discussing the phenomena, refers again to the theory of two forces acting in opposite directions at the two extremities of the strata, and suggests in addition the elevating action of gaseous or melted matter beneath, omitting, however, to account for the general southeasterly direction of the dip.

As the priority of our views in respect to the fact of an inverted and folded structure throughout the chain from Virginia to western Massachusetts, is, we think, clearly established, by our several publications above cited, we can only ascribe the omission, on the part of our esteemed friend, Prof. Hitchcock, distinctly to recognize it, to the insulated manner in which our descriptions and general views have appeared in our Annual Reports and other occasional publications.

Of the Flexures of the Strata, and the Law of their Gradation, from Southeast to Northwest.

The above-described phenomena of the dips in the Appalachian range may, we think, be readily accounted for by the peculiar character of the flexures of the strata. These flexures, unlike the symmetrical curvature usually assigned to anticlinal and synclinal axes, present, in almost every instance, a steeper or more rapid arching on the northwest than southeast side of every convex bend; and, as a direct consequence, a steeper incurvation on the southeast than the northwest side of every concave turn; so that, when viewed together, a series of these flexures has the form of an *obliquely undulated* line, in which the apex of each upper curve lies in advance of the centre of the arch. On the southeastern side of the chain, where the curvature is most sudden, and the flexures are most closely crowded, they present a succession of alternately convex and concave folds, in each of which the lines of greatest dip on the opposite sides of the axes, approach to parallellism, and have a nearly uniform inclination of from forty-five to sixty degrees towards the southeast. This may be expressed in other words, as a *doubling under or inversion* of the northwestern half of each anticlinal flexure. Crossing the mountain chain from any point towards the northwest, the form of the flexures changes, the close inclined plication of the rocks producing their uniformly southeastern dip gradually lessens, the folds open out, and the northwestern side of each convex flexure, instead of being abruptly doubled under and *inverted*, becomes either vertical or dips steeply to the northwest. Advancing still further in the same direction into the region occupied by the higher formations of the Appalachian series, the arches and troughs grow successively rounder and gentler, and the dips on the opposite sides of each anticlinal axis, gradually diminish and approach more and more to equality, until, in the great coal-field west of the Allegheny mountain, they finally flatten down to an almost absolute horizontality of the strata, at a distance of about one hundred and fifty miles from the chain of the Blue ridge or South mountain.

These general features in the physical structure of the Appalachian region, will be best understood by consulting the *Ideal section*, Plate XVI, intended to embrace the prevailing character of the different portions of the chain from the Blue ridge to the western coal-field. Along with this diagram, which embodies the general results of our observations, will be found several *actual sections*, comprising the principal details of structure and topography observed in different parts of the chain, from New Jersey to eastern Tennessee. These cross the belt at nearly equal intervals, and have been selected from a number, all of which equally exhibit the general conditions of structure above described.

To assist in conveying clear conceptions of the diversified and sometimes complicated modes of structure, occasioned by the flexures and foldings of the strata, we deem it important to introduce here two or three new descriptive terms, which seem called for by the necessity of possessing a phraseology adapted to the relationships of the strata about to be detailed. Using the terms anticlinal and synclinal in their commonly accepted sense, we propose to apply the phrases *anticlinal* or *synclinal* mountain or range, to designate ridges formed respectively by a convex and concave flexure of the strata. Every flexure, of such degree as to fall short of producing an inversion of the rocks on the northwestern side of the anticlinal, and the southeastern side of the synclinal bends, we shall call a *normal* flexure; and the dips corresponding to such flexures, as exhibited in transverse sections, we shall denominate *normal dips*. While the phrases, *anticlinal dip*, and *synclinal dip*, sufficiently express the directions of the beds, due to the concave and convex flexures, we propose the term *monoclinal*, to signify a sameness in the direction of the dip, and shall term a mountain or valley, in which such sameness prevails, a *monoclinal* mountain, or *monoclinal* valley. As briefly expressive of the whole concave and convex flexure, we propose to use the terms *arch* and *trough*.

Conceiving a plane to be extended through the apex or most incurved part of each of the concentric flexures in an anticlinal or synclinal bend, so as to occupy a medial position between the two branches of the curve, we propose to call this plane the *axis-plane*. Where the flexure is perfectly symmetrical on both sides of the plane, and the dip on the one side, therefore, equal to that on the other, it is evident, that the axis-plane will have a vertical position. In the Appalachian region, however, and, as we believe, in nearly all other disturbed chains, where the phenomena of flexure are exhibited on a scale of much extent, these planes are inclined to the perpendicular in a greater or less degree, according to the energy of the inflecting force. In the region before us, the dip of the imaginary plane is almost invariably to the southeast, the amount of the deviation from the vertical altitude diminishing progressively, as we cross the chain towards the northwest. A corresponding law of the axis-planes will, we believe, be found to obtain, in all extensive groups of axes, the general expression of their relation being, that the dip of the axis-planes is always *towards* the region of maximum disturbance. From the position thus possessed, by the axis-plane, it will readily appear, that its intersection with a horizontal line connecting the southeast and northwest branches of an anticlinal flexure, will lie nearer to the northwestern branch, and that the reverse will be the case in a synclinal bend. For these relations, see Diagrams, Plate XVI.

Character of the Flexures in each of the Nine Divisions of the Appalachian Chain.

While the flexures of the strata of the Appalachian chain every where conform to the general type above described, they display in each of its great subdivisions, some one or more prevailing characters, marking, as we think, the degree of energy, and the directions of the disturbing forces. Of these, as exhibited in the several divisions formerly specified, the following is a brief account.

1. *Hudson River Division.* In this belt, the flexures are, for the most part, of the closely folded type, and the dip is almost invariably towards the southeast, the compressed and oblique plication of the beds extending equally to the hypogene, or primary rocks, of the mountains bounding the valley on the east, and to the lower formations of the Appalachian system, which occupy the valley itself. Northwestward of the valley, this folded condition of the rocks gives place, as in the vicinity of the Catskill mountain, to flexures of the normal form, which, as we advance, become comparatively obtuse.

2. *Delaware Division.* In this curving district, the formations

of the valley, though still often inverted, are not always so, the flexures being less abrupt, and sometimes of the steep normal type. Thus, in New Jersey, in the tract chiefly occupied by the lower Appalachian limestone, the troughs become somewhat open, and admit long, narrow, synclinal belts of the next superior division, the great slate mass of the Hudson river. As we cross this division northwestward, beyond the valley, the flexures soon grow very gentle, and, as a consequence, the same rocks spread themselves out over very wide tracts, imparting to both the geology and topography a comparatively monotonous character. In all these conditions of flexure in this division, we detect the proofs of a less energetic uplifting and bending force, when compared with that which operated on the contiguous straight belts, situated to the north and south, where the close and oblique plications fill the valley, and where the steep normal flexures range further across the chain.

3. *Susquehanna Division.* Here the obliquely folded flexure is the prevalent one throughout the great valley, giving a general southeasterly direction to the dip. This inversion extends even to some distance northwest of the valley, so as to reach the first anthracite basin, in the middle or widest portion of which a southerly dip very generally prevails. The flexures or axes of this division occupy a very broad belt of country, extending from Lancaster county, across to the northern line of Pennsylvania, a space of one hundred and fifty miles.

4. *Juniata Division.* In this region, the strata are generally inverted, throughout the whole breadth of the South Mountain and the great valley. The principal anticlinal flexures of the Middle Mountain-belt, are remarkable for their great height and steepness, and for the frequency with which they bring almost the lowest of the Appalachian formations to the surface. These features, with the unusual breadth of the belt, across which the disturbances of the strata extend, would seem to show, that the forces producing the axes of this region were of unusual energy.

5. *Potomac Division.* This belt is remarkable for the straightness of its principal axes, and for the beautiful manner in which it exhibits the general laws of gradation in the flexures. Upon

its southeastern border, in the Blue ridge and great valley adjoining, there exists a general tendency to an oblique folding or inversion of the strata, though this condition is less predominant than in the two before-mentioned straight portions of the chain, namely, the Susquehanna and Hudson divisions. In other words, the rocks are less completely folded, many perpendicular and some northwestern dips occurring, to form the northwest side of the arches, and, as we advance beyond the valley, the normal curvatures become the prevailing ones. In accordance with this general condition of things, the great valley contains a long central belt of the middle Appalachian formations, included in a deep trough, a feature that could not exist, if the synclinal foldings were as compressed as in the other more inverted districts. This less closely folded state of the rocks appears to extend entirely across the whole undulated belt, the breadth of which, from the Blue ridge to the valley of the Monongahela, is about one hundred and ten miles. Such a feature seems to imply a less energetic disturbing force in this belt than in the district of curving axes adjoining it on the north, where the rocks in the valley are much inverted; and this inference is supported by the fact of the very rare appearance, at the surface, of those lower rocks, the older Appalachian limestone, for example, which occupy anticlinal tracts in the curving belt, and form a conspicuous feature of it.

6. *James River Division.* This district, sharing with the rest all their essential structural features, and displaying, as formerly mentioned, especially in its valley portion, much irregularity in the strike of its strata, and the direction of its generally short axes, is remarkable for a confused blending of the various kinds of flexure, even within a narrow breadth, and for the passage, more frequently than in the previous division, of the folded and inverted flexures into faults. The great valley is here occupied, in part, by the extensive synclinal range of the Short Hill, and the wide, irregular trough, including the Catawba and Fort Lewis mountains, as well as by other minor ridges of the superior rocks, and is marked by the occurrence of a long line of fault, accompanied by inversion, along the southeast side of the Fort Lewis mountain, and by the prolongation, in a variety of curious phases, of

the great fault, which extends along the southeastern base of the Little North or Brushy mountain, hereafter to be more particularly noticed.

7. *Holston Division.* In this region, the folded structure, attaining its maximum limits, assumes the new condition, (evinced, in a few cases, in the preceding district,) wherein the inverted flexures become a series of dislocations, surpassing, for their length, straightness, and parallelism, any other group of faults recorded. By far the greater part of the strata dip in one direction, or to the south-southeast, the downthrow at the faults being invariably on their northwest side. In crossing this region to the north-northwest, after passing for some distance to older and older formations as we approach a line of elevation, instead of meeting with their counterparts, in an anticlinal arrangement, we step at once from some of the oldest of the Appalachian formations, to beds as recent as the European carboniferous limestone, and thus behold in near contact, on opposite sides of the closed gulf, strata, which originally occupied positions in the vertical column, eight thousand feet apart. This abrupt transition may be noticed, many times in succession, in the first thirty miles, going northwestward from the base of the Blue ridge.

8. *Knoxville Division.* As in the instance of the district last described, the whole disturbed space is comparatively narrow. Here, too, in consequence of the numerous inverted flexures and parallel lines of dislocation, the strata are extensively inverted, having, therefore, very generally, a dip to the southeast, and displaying the normal form of flexure but rarely, until we reach the northwestern side of the district. Of this universal prevalence of southeasterly dip, mention is made by Professor Troost, in his 'Annual Reports on the Geological Survey of Tennessee, for the years 1839 and 1840,' and we can confirm his statements by our own observations, made in the northern parts of the district. An interesting feature in this belt, is the analogy which it displays to the other convex, or Juniata division, in the regular or uninterrupted curving of the axes and lines of strike; and, on the other hand, the decided contrast, in this respect, which they both pre-

sent to the two concave belts, where the axes are shorter and less parallel.

9. *Alabama Division.* This disturbed tract, progressively diminishing in breadth, from its commencement in Tennessee to its termination in Alabama, displays the usual inversion of the lower rocks, and the other signs of the presence of oblique flexures, and of that species of dislocation, which results from them, and would seem, from the best information we can collect, to preserve these features of structure without abatement to its extreme southwestern end, where it is finally overspread by the newer secondary and tertiary strata.

Thus, every section of the Appalachian chain, whatever its direction or curvature, offers the same remarkable and beautiful features and gradations in its axes, implying, that the cause of these phenomena was some grand and simple energy, coextensive with the whole margin of the Appalachian Sea, from Canada to Alabama.

Exemplification of the several Modes of Structure.

1st. *Normal Flexures.* Having presented a general outline of the different divisions of the chain, we shall next enter into a description of the several varieties of structure, which distinguish the different parts of it. Flexures of the normal character, constitute, as we have seen, the predominant curvatures of the strata, throughout almost the entire length of this mountain zone, the obliquely folded, or inverted axes, being principally limited to a belt of variable width, along the southeastern side. Of the numerous parallel anticlinal and synclinal ranges, which strikingly exhibit this normal configuration, we shall cite a few examples from Pennsylvania and Virginia, and refer to the engraved Sections accompanying this paper, for details of the dip in each respective portion of the chain. In the Knobly mountain, the most westerly of the great anticlinal flexures, situated to the southeast of the coal region, the normal character is maintained, with great uniformity, throughout a distance of upwards of fifty miles. It commences with the first appearance of the axis, in the immediate vicinity of Cumberland, and continues, as the mountain augments in breadth and height, in its extension to the southwest. Still further in that direction, beyond the intersection of the axis with the North Fork of the Potomac river, in Pendleton county, Virginia, the dips on the northwestern side of the arch become either perpendicular, or slightly inverted; and this attitude they retain for a further distance of about forty miles. Traced from its first appearance, a little southeast of Cumberland, to its termination in the anticlinal valley of Crab Bottom, this axis offers a beautiful illustration of the prevailing regular gradation, in the amount of inflection which the strata have undergone, in different portions of the line, as dependent on the varying intensity of the elevating and bending force. At first, the lowest rocks, which the axis exposes, are the red and calcareous shales (F. V,) or Clinton group. Here the flexure, though more abrupt on the northwest than on the opposite side, does not exceed a moderately steep normal curvature. Further to the southwest, where the next inferior formation (F. IV, Shawungunk grit) emerges to the surface, and expands, as we advance, giving an imposing breadth and elevation to the ridge, we find the northwestern part of the arch so increased in steepness, that its dips are nearly vertical. The axis, becoming still more developed as we proceed, the next inferior formation (F. III, Hudson slates) now makes its appearance, and rapidly expands into an anticlinal valley, which separates the broad and lofty mountain range into two distinct ridges. The strata of the northwestern of these crests have a vertical, and even, sometimes, an inverted dip. Still further, in the same line, a yet lower formation rises, the great lower Appalachian limestone (F. II), and occupies a large portion of the breadth of this anticlinal valley. The dip of the rocks in the northwestern ridge now becomes, as might be anticipated, very frequently inverted. Passing this culminating portion of the axis, its further prolongation to the southwest is marked by the foregoing phenomena, in a converse order, until finally, near the head-waters of Back Creek, the divided strata of the higher groups once more unite, to form a gentle normal flexure, in the inconspicuous ridge at the southwestern termination of the axis.

In the *Bull Pasture* mountain, which traverses Pendleton and a portion of Bath counties, in a line southeast of the range above described, we have an example of the retention of the normal structure throughout the entire length of the axis, embracing a distance of more than fifty miles. Here, also, we witness the gradual steepening of the flexure, as lower and lower groups are elevated to the surface, although the whole amount of the elevatory movement, having, in this case, been less than in that of the Knobly axis, it has nowhere produced an actual inversion of the dip.

The interesting relation here disclosed between the steepness of the flexure, and the amount of actual rise of the rocks, at different points in the axis, extends to all the shorter, as well as the most prolonged of these lines, and applies to every part of the Appalachian chain, constituting a law of structure, connected intimately with the theory of the nature of the folding movement.

Besides the above cases, we may cite, for Pennsylvania, the great axis of Wills's Creek mountain, that of the Black Log anticlinal valley, and the still more prolonged one of the Kishicoquillas valley, and Jack's mountain, in all three of which the normal type is preserved, while the relation between the degree of developement of the axis and the steepness of the northwestern dips, as already announced, is uniformly displayed.

2nd. *Inverted Flexures.* As indicated in the general or ideal Section of the chain, the flexures, accompanied by an inversion of the strata on the northwestern side, are of most frequent occurrence along the southeastern border of the Appalachian chain. In some districts, however, these foldings extend, for a considerable distance, across towards the middle of the belt, a fact well exemplified in the general southeasterly dip of the Pottsville coal-field. The passage from the normal to the closely folded inverted curvature, as the developement of the axis increases, is a phenomenon well observed in a number of the principal anticlinal ranges in Pennsylvania and Virginia, among which may be instanced the Bald Eagle axis, in the former State, and the Jackson's mountain and the Wolf creek axes, in the latter.

The Bald Eagle axis, commencing some miles south of Hollidaysburg, and ranging west of the centre of Sinking and Nittany valleys, and through the middle of Nippenose valley, terminates south of the Allegheny mountain, a number of miles northeast of Pennsboro'. It thus embraces, in its long and gentle sweep, a distance of about one hundred and twenty miles. For many miles of its length, at each extremity, where it lifts only the middle Appalachian rocks, it displays simply a gentle normal flexure; but nearer the middle of the line, where it elevates lower and lower formations, and finally brings to the surface the great Appalachian limestone, the arch gradually steepens, until it embraces a vertical, and occasionally an inverted dip, along the Bald Eagle mountain, from the Little Juniata to Bellefonte.

The Jackson's mountain axis commences near the northwestern flank of the Fork mountain, in Pendleton county, Virginia, and continues in a nearly straight direction in Jackson's mountain, and the anticlinal valley of the Warm and Hot Springs, as far as Jackson's river, in the neighborhood of Covington. This comprises a length of about seventy miles. Traced from its northeastern extremity to within a few miles of the first exposure of the lower Appalachian limestone, the mountain continues single, and displays a normal, but regularly increasing arch, with a steepening northwest dip. But further towards the southwest, from the commencement of the anticlinal valley, in which the limestone rises, to the lower end of the Falling Spring valley, the mountain divides itself into two ridges, that on the northwest exhibiting both perpendicular and inverted dips. Beyond the Falling Spring, the valley rapidly closes up again by the subsidence of the axis, and at Jackson's river nothing remains of this remarkable range but a low ridge, composed of the higher rocks, arching over in a moderately obtuse normal flexure.

The Wolf creek axis, in Virginia, rises near the head of Stony creek, a little southeast of Peters's mountain, and ranges along the southeast side of Peters's, and the northwest side of Wolf creek mountain, and Rich mountain, for a distance of between seventy and eighty miles. Throughout nearly the whole of its length, this axis lies in the lower Appalachian limestone, in which there is an inversion of the dip on the northwest side of the axis.

plane, that sometimes passes into a fault. This inversion is strikingly displayed along the southeastern base and slope of the synclinal mountain, called Buck-horn ridge, adjoining the axis on the northwest, where the strata of this side of the mountain are folded over so as to lie in almost parallel posture with the corresponding rocks on the opposite or northwestern side of the trough.

3rd. *Flexures broken, or passing into faults.* A feature of frequent occurrence in certain portions of the Appalachian belt, is the passage of an inverted or folded flexure into a fault. These dislocations, preserving the general direction of the anticlinal axes, out of which they grow, are usually prolonged to a great distance, having, in some instances, — for example, in southwestern Virginia, — a length of about one hundred miles. These lines of fault occur in all cases, along the northwestern side of the anticlinal, or the southeastern side of the synclinal axis, and never in the opposite situation. This curious and instructive fact is best seen by tracing, longitudinally, some of the principal anticlinal axes of Pennsylvania and Virginia. From a rapidly steepening northwestern dip, the northwestern branch of the arch passes through the vertical position, into an inverted or southeastern dip; and at this stage of the folding, the fault generally commences. It begins with the disappearance of one of the groups of softer strata, lying immediately to the northwest of the more massive beds, which form the northwestern summit of the anticlinal belt. The dislocation increases as we follow it longitudinally, group after group of these overlying rocks disappearing from the surface, until, in many of the more prolonged faults, the lower limestone is brought, for a great distance, with a moderate southeasterly dip, directly upon the carboniferous formations. In these stupendous fractures, of which several instances occur in southwestern Virginia, the carboniferous limestone being brought into close proximity to the great lower Appalachian limestone, a portion of which, even, is occasionally buried, the thickness of the strata ingulfed cannot be less than seven thousand or eight thousand feet.

The position of the strata along some of these extraordinary dislocations may be seen in the Sections C, D, E, (Pls. XX, XXI.)

accompanying this paper. Sections D and E represent (at *a*) the conditions prevailing in the prolonged fault on the northwest side of the axis of the Sweet Spring Valley. This axis, in its normal state, brings up the great lower Appalachian limestone, flanked on the northwest by the overlying slate and sandstone, which, together with the northwestern half of the limestone, have a steep northwestern dip. More towards the southwest, this dip augments; the strata on the northwest side of the axis soon become vertical, and thence quickly pass into the inverted position. At this point, the fault begins, being marked, at first, by the disappearance of a portion of the slates (For. III) and variegated shales (For. V), adjoining the thick-bedded sandstone (For. IV), which forms the framework of the ridge, that bounds the anticlinal valley on the northwest. It presents, as it extends southwestward, a continually augmenting hiatus in the geological series, ingulfing in succession nearly all the strata between the limestone of the axis, and the carboniferous limestone, and exhibiting an inversion of the latter, for some distance across to the northwest of the line of fault. The inversion of the strata near the dislocation on its northwest side, giving them a southeasterly dip, becomes less as we recede from the fault. By a gradual transition, the dips become perpendicular, then steeply inclined to the northwest, and eventually, at no great distance, very gently so; after which, a few broad and feeble undulations succeed, as we pass into the coal region. Tracing this line of fault, in a southwesterly direction, for a distance of upwards of one hundred miles, we encounter, at various points, portions of the ingulfed strata, which occasionally reappear to form isolated knobs or short ridges, inclosed between the two great limestone formations (F. II, and F. XI), the crushed edges of which, however, are usually not thus separated. The detached masses, so curiously wedged into the chasm of the fault, consist of small remnants of the thick slate group, which underlies, at some interval, the carboniferous limestone, and of the hard white sandstone (F. IV, Shawungunk grit), which constitutes, as it were, the bony skeleton of our principal Appalachian ridges.

Sections C, D, and E, show (at *c*) the conditions usually prevailing in a very remarkable line of fault, which extends, with but few interruptions, along the western margin of the Great Valley of Virginia, throughout the chief part of its length. The ridge, which bounds this valley on the northwest, and which, as we pursue it southwestward, assumes successively the names of Little North mountain, North mountain, and Brushy ridge, marks the position of this extraordinary dislocation. With the exception of several intervening spaces, some distance south of the James river, in which the normal, or northwestern dip of the rocks in this ridge is in the main retained, its strata assume an inverted attitude, the great lower Appalachian limestone of the valley, lying on the slates of the next superior group, and these, in turn, resting with a southeast dip on the white sandstone, while the adjoining formations of a still higher position in the series, are either partially or entirely swallowed in the fissure. The sandstone itself, which, throughout a part of the State, gives prominence to the ridge, and the slates intervening between it and the limestone, are both more or less ingulfed; and, in some parts of the line, the whole mass of the mountain has disappeared; so that the observer may cross, by a single stride, from the very ancient limestone of the valley, to beds but little lower in the series than the carboniferous limestone. Still further along the line, the formations thus lost are seen partially rising again into view, the white sandstone (F. IV) first showing itself in insulated knobs or patches, and afterwards in a continuous, low, and irregular ridge, in which some of the other missing groups also reappear. Between a point a few miles south of the intersection of the James river with this ridge, and the neighborhood of Abingdon, near the Tennessee line, this fault assumes a more uniform, though, perhaps, a still more extraordinary character. At the passage of the river, the massive range of the North mountain presents no other indications of this line of fault than a partial inversion of the thick beds of sandstone, of which it principally consists, and an entire overthrow and partial burial of the slates which flank it on the southeast. But a few miles further towards the southwest, the whole of this enormous mountain mass sinks from view, excepting an isolated knob here or there, of the harder rocks, which, for a short distance, serve to mark the irregular progress of the fault. At length, the dislocation attains what may be called its maximum intensity; the slate, and not unfrequently, the limestone of the valley, resting in an inverted attitude, with a gentle southeast dip, directly upon the southeasterly dipping grits and shales of the formation next beneath the carboniferous limestone, here constituting the southeastern slope of the Brushy mountain. The seam of semi-bituminous coal, generally embraced between these strata, is, in virtue of the dislocation, made to assume the anomalous condition of passing *under* the valley limestone at a distance of only a few hundred feet, dipping in the same direction with that rock.

Preserving these features, with but little variation, throughout its whole course to the southwest, this extraordinary fault extends, in an almost perfectly straight line, along the southeastern slope of the Brushy mountain, from near the head of the Catawba creek, to the vicinity of Smyth court-house, a distance of more than eighty miles. At no point, in this line, are the rocks which originally formed the counterpart to the strata of the Brushy mountain, and which are, in fact, represented by those of the Little North mountain, in the northern part of the line, even partially restored to the surface; so that this stupendous dislocation is to be viewed as having actually swallowed up the rocks of the southeastern half of a large synclinal basin, of which the Brushy mountain remains as the other half.

4th. *Of the distribution of the axes in groups.* Wherever, in the Appalachian chain, we become minutely familiar with the undulations of the strata, we find it impossible to resist the conclusion, that the axes arrange themselves in natural *groups*, the individual flexures showing a close agreement in their length, mutual distance, straightness, or curvature, and in the extent and style of the arching. In those districts which are crowded with normal axes, such as the Susquehanna and Juniata divisions, many such groups attract our notice. Each of these assemblages of axes being generally distinguished by some special character, we are inclined to regard the comparison and analysis of their several features as of the very highest importance, in those investigations of geological dynamics into which the whole subject of flexures must evidently lead us. The limits of the present memoir preclude a detailed description of each group of axes, contained even in the States of Virginia, Pennsylvania, and New Jersey, where we have principally explored them, and altogether forbid any attempt to apply our theory of flexures to an explanation of the local features, distinctive of each group. We shall, therefore, content ourselves with describing two or three of these collections of axes, more for the purpose of proving our present general statement, that the axes do thus assort themselves, than with a view to discuss the secondary causes connected with their peculiarities.

The great divisions, into which the entire chain naturally divides itself, are alone abundantly significant of this essential tendency of the axes to form groups. For, upon a general view of the whole chain, each of the nine extensive belts, into which we have divided it, becomes one comprehensive group, in which all the axes display certain common characteristics of straightness or curvature, as the case may be. Lest, however, it should be supposed, that this grouping of the flexures is only to be recognized when we embrace very extensive subdivisions of the chain, we shall refer to smaller tracts, and show, that axes of all dimensions thus associate themselves. An excellent instance of a group is to be seen in a district composed of the northern half of Mifflin, and the southeastern half of Centre counties, in Pennsylvania. The axes which belong to the general convex system of the Juniata accord remarkably, in all their essential features. They are either of the normal type, with steep northwestern dips, or they have the northwestern part of the arch slightly inverted. They are almost exactly parallel, curving a little in obedience to the general sweep of the chain, while they are singularly equidistant from each other. As each flexure possesses nearly the same transverse form and dimensions, they bestow a strikingly regular and symmetrical topography on the whole region, the great lower Appalachian limestone and slate groups rising to the surface in a series of long and parallel anticlinal valleys, while the overlying sandstones compose so many intervening, steep, straight, and regular synclinal ridges.

Another well characterized belt of flexures fills the Lewistown valley in Pennsylvania; applying this name to the whole of the long, natural valley, which extends from the Susquehanna to the Juniata, southeast of Jack's mountain. In a breadth of about six miles, there are here usually from five to six long, parallel, and gently curving anticlinal axes, all of them of the normal form, resembling each other very nearly in the steepness of the dips, or average degree of flexure. The lowest rocks, which they lift to the surface, are the variegated shales, (F. V, Clinton group,) and the highest, which their intermediate troughs have retained, are the sandstone (F. VII,) and the overlying slates of F. VIII.

A third very natural group of flexures is to be noticed in the eastern part of the middle anthracite coal-field of Pennsylvania. The axes in question separate that region into an assemblage of small, parallel coal basins, of which the Beaver Meadow basin is one. Like the previous groups, these axes are characterized by their remarkable parallelism, their similarity in length, their exact equidistance, and their gentle gradation, approaching to equality, in the degree of the flexure. They all of them bring to the surface the conglomerate which next underlies the coal, and the troughs, which they form, contain about the same moderate depth of coal measures, growing shallower, however, to the northwest. This collection of axes, unlike the two groups before described, belongs to a straight system.

If it were desirable, we might extend the enumeration of the groups of axes to every part of the Appalachian chain; but abundant evidence has been furnished, to show that our anticlinal axes are not irregularly distributed, but maintain relations with each other, which require that they should be classified and studied collectively. Their generic resemblances examined, they will be found to exhibit general laws and analogies, that cannot fail to lead to some highly curious results concerning the forces, which from time to time have thus undulated the earth's crust. That this curious and most instructive department of geological dynamics has escaped, until lately, the attention of the best investigators, we can only attribute to the fact, that in Europe, no belt of axes, equal in extent to the Appalachian system, has come within the notice of geologists. Before a philosophical theory of flexures can be framed, large opportunities must be had for classifying their phenomena, and tracing their laws of gradation.

It is a curious and important fact, connected with this group of axes, that in certain cases, chiefly, we believe, in wide and deep troughs, the included smaller axes or wrinkles, though parallel to each other, are not parallel to the general synclinal axis of the basin, in which they occur. This feature is obvious in all the deep anthracite coal-basins of Pennsylvania, especially near their terminations. These lesser, subordinate axes, generally have a strike parallel to that of one of the great flexures bounding the basin; but, on account of the convergence of the sides of the trough, they are necessarily more or less oblique to the opposite margin. They are, therefore, so many long, parallel warpings of the strata, conforming to one boundary, but abutting acutely against the other. Sometimes, indeed, they cross the basin very gradually, or pass almost longitudinally, from one side to the opposite, and die out, as wrinkles on the slopes which bound the basin. That they have originated in an inequality in the energy of the linear forces concerned in bending and elevating the rocks along the principal flexures, and arise, therefore, from an actual warping of the strata, seems altogether probable. If so, they are secondary consequences of those more general and extended movements, which give existence to the grander flexures, in whose folds they lie. To describe all the phenomena relating to these minor assemblages of axes, the full investigation of which, as it concerns the mining operations of our coal-fields, is, perhaps, the most useful practical inquiry that the geologist can undertake, would demand a body of minute details, only to be elucidated by a general map of the flexures, not yet ready for publication.

5th. *Parallelism of the axes in each group.* The parallelism of the several axes or lines of flexure, which compose a group, either extensive or limited, is one of the most remarkable relations. The descriptions already furnished show, that it prevails in every portion of the chain, whether straight or curved, and extends even to the members of the smallest groups. A striking exhibition of this mutual parallelism may be noticed among the inverted and normal flexures in the great valley, in that part of the chain which we have called the Potomac division. Some of the larger axes are there prolonged, side by side, for nearly one hundred miles. The same fact may be equally well seen in the great curving axes of the Juniata division, and amongst those most remarkably persistent flexures, which divide the parallel bituminous coal-fields northwest of the Allegheny mountain, in Pennsylvania and Virginia. It is yet more strikingly displayed, perhaps, in the long and singularly straight axes and faults of the Holston region, in Virginia and Tennessee, where the lines, both of flexure and of dislocation, maintain almost exactly the same distance from each other for upwards of one hundred and fifty miles. This parallelism, however, is after all but approximate, though, as many of the adjacent axes of a group in a length of say fifty miles, observing a mean distance of not more than two or three miles, seldom approach or recede more than a fourth of this space, we are justified in seeking for some theory which shall explain so conspicuous a relation.

6th. *Of the great length of some of the axes.* Perhaps nothing astonishes the geological traveller in the Appalachian chain, so much as the enormous length and persistency of many of the axes. Tracing these lines of flexure longitudinally, they will not unfrequently be found to range for eighty or one hundred miles, with but little deviation either from perfect straightness, or from a uniform gradual curvature, parallel to the general inflection of the division of the chain, in which they are included. This astonishing regularity and length is, perhaps, best noticed in the axes of the northwestern side of the belt, where they frequently exhibit a steady curvature, for more than one hundred and fifty miles. Whether the southeastern axes are less prolonged, or whether their crowded condition often conceals the continuity of their range, are points we do not at present undertake to decide. Among the very numerous instances of long and regular axes of the steep normal type, we must specify, in the Susquehanna region, the straight axis of Montour's ridge, which extends about eighty miles; in the Juniata division, the beautifully inflected axis of Jack's mountain, continuous for more than ninety miles; in the Potomac division, the straight axis of Wills's creek mountain, ninety miles in length, and also that of the Knobly mountain, nearly a prolongation of the last, itself a hundred miles long. To these we may add, for the Holston region, the straight axis of Wolf creek, and that of the Clinch mountain, the former of which is about one hundred miles, and the latter more than one hundred and twenty miles in length.

It is probable, that numerous axes of the folded or inverted type, quite as extended, exist in the great valley, and the adjacent belt of ridges on the southeast side of the chain, and we have already seen, that where some of the steep normal and inverted flexures pass into dislocations, they have a length even exceeding that of any of the axes above referred to. If we turn to the more depressed normal axes of the western coal region, we shall find, that that which lies next northwest of the Potomac basin, is at least seventy miles long, that of the Negro mountain ninety miles, that of Laurel hill at least ninety miles, and that of Chestnut ridge, or West Laurel hill, more than one hundred miles in length; and our geological maps will exhibit, in other less well-known portions of the same belt, a series of similar obtuse flexures, of even still more extended length.

7th. *Of the curving of axes.* It is needless to add much to what has already been said or inferred concerning the horizontal inflection of the axes in some groups, since the changes of strike mentioned, while tracing the great divisions of the chain, involve a parallel bending of all the principal and most influential flexures individually. Considering the enormous extent of *warping*, which the crust must have undergone, and which we can infer that it did undergo, from the evidence afforded in the lesser, or secondary flexures, and also from the nature of the faults, the prevailing continuity and graceful, curving outline, witnessed in many of the inflected axes, are truly remarkable. There are cases, as in that of the Jack's mountain flexure, where a continuous axis sweeps for ninety miles, to undergo a change of strike of as much as forty-five degrees, without once taking on a serpentine or contrary incurvation, or manifesting any considerable inequality in the bending. Instances of such extraordinary length and regularity, are, however, comparatively rare, and are confined chiefly to the divisions of the chain in which the curvature is convex to the northwest. A more common linear form among the longer curving axes, if we except those, — the longest and most regular of all, — which traverse the great northwestern coal region, is one which embraces a partial discontinuity of the line, at one or several points. This discontinuity is, in most cases, only partial, being of the nature of a warp, the anticlinal arch embracing, generally on its southeastern slope, another flexure, which either immediately, or at a moderate distance, becomes the principal, and finally the only, anticlinal crest, while the original summit, in its turn, subsides upon the flank of the other. In such cases, where the two closely overlapping flexures are included within one general anticlinal arch of about the same average breadth and height as the parts which contain the flexure in its single state, and where the relative depression embraced by the warp is comparatively trivial, there seems no impropriety in considering the whole as one great undulation, locally disturbed, from some inequality in the bending or resisting forces. The warp will, in fact, be found, in such cases, to occur commonly near the central portion of the line, where the maximum degree of flexure and elevation, in all strictly continuous axes, has been experienced, and exactly where we would naturally look for the greatest irregularities in the movement of the strata.

When the bearing of the various phenomena of curving axes upon some of the most interesting questions of geological dynamics is contemplated, the importance of a critical investigation of all their modifications of form cannot fail to be recognized. Besides demanding their proportion of attention, in any theory which attempts to explain the origin of axes, generally, these curving axes of our Appalachian region merit particular examination in another light. They appear to contradict directly the well known hypothesis of the distinguished French geologist, M. Elie de Beaumont, which supposes, that a constant relation subsists between the epoch of elevation, and the directions or strikes of the lines of disturbance. These curving axes constitute so many intermediate links between the straight divisions of the chain, in which they terminate at their opposite extremities, and they are demonstrably of the same age with the rectilinear flexures, with which they there alternate. But the different sections of the chain, thus referred to one general succession of elevatory movements, differ from each other in their strike as much, in some instances, as forty or forty-five degrees; and, if we include systems of axes not contiguous, but the sameness of whose date is equally demonstrable, — as when we compare the Vermont and the Holston axes, — the difference in direction is even as much as sixty degrees. Here are extensive mountain belts, each upwards of two hundred miles in length, possessing unequivocally the same epoch, differing in the direction of the elevatory movement much more than some of the European systems of widely different geological age. It is obvious, then, that the generalization of M. de Beaumont, if in accordance at all with nature, is only so as it relates to the general direction of entire mountain systems, and not to the course of special groups of axes, however extended.

Description of a Series of Sections across the Chain.

Section A, (Pl. XVIII.) This Section extends from the South mountain, in Berks county, Pennsylvania, through the anthracite basins, to the Allegheny mountain, in Luzerne county, and exemplifies the usual features of structure prevailing in the Susquehanna division of the chain, showing the folded and inverted condition of all the rocks in the South mountain and great valley, also the steepness of the northwestern sides of the flexures in the rest of the belt, and the beautiful grouping of the axes, especially in the middle anthracite region, combined with a general progressive reduction in the abruptness of all the curves and dips. It likewise shows, that the hypogene strata of the South mountain are included in the same general system of flexures with the Appalachian strata.

Section B, (Pl. XIX.) This extends in a west-northwest direction, from the South mountain, in Cumberland county, Pennsylvania, through the Broad Top coal-field, to Chestnut ridge, in

Indiana county, and offers a striking illustration of the existence of exactly the same structural features, in the curving region of the Juniata, as the other shows in the straight one of the Susquehanna. The folded or inverted axes occupy the belt of the South mountain and great valley, northwest of which they are succeeded by a broad belt of steep normal flexures, several of which lift to the surface nearly the lowest formations of the system. This Section also displays the manner in which the western coal region is divided by the wide and gentle flexures northwest of the Allegheny escarpment.

Section C, (Pl. XX.) Our third Section crosses the chain in a direction from the Blue ridge, at Ashby's gap, in Virginia, through Winchester and Romney, to the commencement of the coal rocks, on the Front ridge of the Allegheny mountain. It exhibits normal flexures everywhere but in the Blue ridge and great valley. In the Short hill and Blue ridge, at the southeast end of the Section, the sandstones, forming the lowest group of the Appalachian system, are seen in folded anticlinal flexures, which equally affect the older metamorphic rocks, the whole of the northwestern slope of the Blue ridge presenting an inverted or southeastern dip. The general southeasterly inclination of the axes-planes, or, which is the same thing, the greater steepness of the northwestern, compared with the southeastern dips, is very uniformly exhibited in this Section. The rocks of the Little North mountain are here shown to be inverted, presenting (at *c*) one of the phases of the prolonged fault, formerly alluded to.

Section D, (Pl. XXI.) This Section crosses the chain from a point high up on the south fork of the Roanoke river, in Virginia, to the northwest base of the Peters's mountain, near Union. Lying in the James river division of the chain, it exhibits the rather confused mixture of normal and inverted flexures and faults, for which that district is remarkable. On the southeast, are seen the bold flexures of the strata of the lowest of the Appalachian formations, here of extraordinary thickness, and forming a lofty mountain range, while, immediately behind them, on the southeast, are seen the numerous foldings of the ancient metamorphic strata. A fault (at *d*) at the southeast base of the

Fort Lewis mountain, shows Formation II thrown over upon VIII. Some miles towards the northwest (at *c*) is the great fault of the Little North mountain, presenting Formations II and X, in contact, the former being uppermost. Near the northwest termination of the Section (at *a*) is seen the fault on the northwest side of the Sweet spring, or Peters's mountain axis, here showing the contact of For. II with the upper part of For. VIII; the remainder of the latter, together with the other intervening formations, being lost. In this part of the Section may be seen the rapid passage of the higher rocks, from inversion to verticality, and thence into a very gently undulating and horizontal position, towards the northwest.

Section E, (Pl. XXI.) This Section extends from the Poplar camp mountain, in Virginia, near the mouth of Reed creek, in a north-northwest direction, to the commencement of the coal rocks, immediately northwest of Abb's valley. Lying in the Holston division, in the southwestern part of Virginia, it traverses nearly all the great parallel lines of fault, for which that region is so remarkable. At its southeastern extremity we notice the lowest formation of the Appalachian system, bent over into an inverted position, and resting upon the next superior rock, the great lower limestone, (For. II.) Steep normal, and also folded flexures, extend across the valley to the Cove mountain, at the southeast base of which we meet with a line of fault (at *d*), bringing in contact Fors. II and VIII, with the usual inversion of the former. Beyond this, to the northwest, near the southeast base of Brushy ridge (at *c*), is the great dislocation referred to on previous occasions, and which here brings together Fors. II and X. Still further towards the northwest, in the valley of Walker's creek, on the northwest side of an inverted anticlinal axis of For. II, a similar fault occurs (at *b*), with the same hiatus of the intervening formations. Beyond this, or northwest of the Wolf creek axis, we see (at *a*) an extension of the great fault previously described as running along the northwest side of the Sweet spring, or Peters's mountain axis. A few miles further, we come upon the last, or most northwestern line belonging to this division of the chain.

Increasing Interval between the Axes as we advance Northwestward.

It is an interesting general fact, that the space between the axes, or, more properly, the amplitude of the undulations, increases as we cross the chain northwestward. This is represented in the ideal Section, and is equally apparent in the actual Sections which accompany it, being strikingly visible in that (Section B) intended to illustrate the structure of the Juniata region. Although distinctly noticeable in the northwestern side of the belt, the gradation prevails equally in the middle and southeastern tracts, though in the latter the numerous minor flexures, with the interference of groups of different dimensions, prevents our at first perceiving the law in all its simplicity and exactness. Towards the southeastern side of the chain, the flexures become so numerous, and are so often folded or inverted, as, in most cases, to render the comparison of their distances impracticable. Yet, even in this quarter, the general truth appears, in the diminished space between the foldings, as we cross the Great Valley, southeastward. Taking in the whole breadth of the chain, the prevalence of the rule is obvious, no matter by what Section we cross.

PART II.

Theory of the Flexure and Elevation of the Strata, founded on the preceding Phenomena, — combined undulatory and tangential Character of the Movement.

That the movement which produced the permanent flexures was compounded of a wave-like oscillation, and a tangential or horizontal pressure, both propagated northwestward across the disturbed belt, is plainly indicated by the oblique character of nearly all the anticlinal and synclinal curves, both those which are closely folded, and those which are obtuse. This oblique inflection of the strata will, we confidently believe, be found to prevail as the regular form of all anticlinal axes, in every part of the world. It appears to imply a powerful tangential movement, always operating in the same direction for the same region, during the epoch of disturbance. A merely vertical force, exerted either simultaneously or successively, along a system of parallel lines, could only produce the same number of *symmetrical* anticlinal arches, while again, a horizontal or tangential pressure, uncombined with an alternate upward and downward motion, at regular intervals, could not possibly result in a system of parallel folds, or axes, or lead to any change in the position of the strata, beyond an imperceptible bulging of the whole tract, or else a confused rumpling and dislocation, dependent on local inequalities in the thickness or resistance of the crust, in different spots.

That the *wave-like* flexures of our Appalachian strata are the result of an actual *onward, billowy movement*, proceeding from beneath, and *not* of a folding due simply to some *great horizontal or lateral compression*, will appear from the following considerations. In the first place, it is absolutely impossible to conceive, that *any* force, of an intensity however vast, exerted in the direction of a tangent to the earth's surface, could by itself shove a thick and imperfectly flexible crust into a system of close *alternate* folds. Beyond the imperceptible bulging of the whole tract laterally from the line of application of the force, no flexure could arise, other, perhaps, than some diminutive, but *irregular* plications, caused by inequalities in the strata or crust, and these, it is needless to remark, would be destitute of any law of parallelism and gradation, such as that which strikingly characterizes the Appalachian and other regions. No *system of narrow waves* of the strata, however flat, could originate from the most enormous lateral pressure, if unaccompanied by some vertical oscillation, producing parallel lines of easy flexure. Precisely such an alternate movement would ensue, if a succession of *actual waves* on the surface of the subterranean fluid rock rolled in a given direction beneath the bending crust.

The inadequacy of the tangential or horizontal force, as a cause of the Appalachian axes, is still further obvious, when we consider, that no igneous rocks, of any sort, were thrust to the surface, except in the belt of country bordering this broad system of flexures on the southeast, and that, therefore, if the axes or foldings were produced solely by lateral pressure, the whole force must have been propagated from the lines, where the wedging in of the igneous matter occurred in this southeastern region, to the remotest of the axes, through all the intervening folds. But, consistently with mechanical analogies, such a transmitted force, instead of producing the gentle gradation of flexure, which we behold, would have expended itself in merely compressing or crushing the contiguous tracts across a narrow belt, a little widened by a succession of these tangential actions. The narrow disturbed belt would abound in irregular contortions, and beyond it we should suddenly come to the strata in their original horizontality.

That such would really be the effect of the supposed horizontal action, is clearly proved by the singularly undisturbed condition, already stated, of the strata immediately, and for some distance, northwest of all our great lines of dislocation. Along these lines, the uniform inversion, and the crushed and contorted state of the higher rocks, immediately northwest of the fracture, indicate plainly an enormous lateral thrust in that direction from the fault. Yet, even where the greatest energy of this force is manifested, the inversion or other disturbance extends only for a few hundred yards northwest of the fissure, while a little beyond, the horizontal posture of the rocks has been even less changed than in parts of the same region, where no fault exists.

Even granting, that such a force, transmitted to a great distance across the chain, were capable of bending the strata of the remoter tracts into gentler undulations, the flexures on their northwestern sides ought to be relatively still steeper than they are, for in that quarter the curves are almost symmetrical. On the other hand, this near approach to a symmetry of curvature in the remoter axes, is an obvious consequence of the greatly reduced force and size of the nearly exhausted waves.

The widening of the interval between the axes, as we go to the northwest, is another general fact, which, while it finds a ready explanation in the hypothesis of a violent undulation of the strata, would seem to be wholly at variance with the operation of a gradual and prolonged pressure, exerted northwestward. Conceiving the various degrees of inflection witnessed in different parts of the chain to have resulted from a long-continued pressure, we should be compelled to admit, that the southeastern side of the tract had had impressed upon it successively all the different gradations of flexure met with throughout the chain, and thus we should have to suppose, that the closely folded, crowded axes of the great valley were slowly developed by a force that, in its earlier stages, produced every where only wide and gentle arches. Yet, if such was the case, why do we not recognize a yet more uniform or gradual transition in the dimensions of the axes, than our Sections show. If the steepness of the flexures measures thus their age, why, it may be asked, are those of the same group so various in this respect, while their intimate relations to each other, in respect to parallelism, gradation of distance, and dip, plainly prove them to have had a contemporaneous origin? If a long period was consumed in their production, why did there not take place, by virtue of the simultaneous denudation and deposition which must have been in progress, a constantly unconformable superposition of the new deposits, as the axes slowly rose above the level of the water?

But, while the observed variety in the magnitude and steepness of the flexures thus makes it incumbent on the advocates of such a theory of the gradual formation of axes, to admit, that the folded and closely crowded ones have arisen out of broader and normal curves, the general tenor of their doctrine of progressive and cumulative actions, implies, that the short and narrow flexures were produced first, and that some of them were enlarged into the vastly bolder and longer axes, which abound in many parts of the same region. This, however, seems an insuperable difficulty, since, if we suppose the breadth and length thus steadily to increase, a great number of intervening flexures and foldings would be necessarily obliterated or reversed.

But, quitting the theory of a gradual horizontal pressure, another hypothesis suggests itself, as likely, in the present stage of geological speculation, to be offered in explanation of the structural laws we have described. It may be urged, that *a* *prolonged upward tension, or pressure exerted along a single line,* might gradually create a broad and lofty anticlinal flexure, and might, *by a mere shifting of the line*, into positions always parallel to its first one, accomplish in time the elevation of all the axes of any of our Appalachian groups. Such a supposition would, doubtless, account for the simple features of a symmetrical flexure; but it would afford no clue to an explanation of those beautiful relations, which prevail between the form of the flexures and their position in the groups, to which they appertain, or to the fact of their assemblage into groups; and these are among the most interesting general facts, which a theory of flexures is called upon to explain. How could a merely vertical force, applied to the interior surface of the crust, either along a narrow line, or over an elongated elliptical, narrow zone, produce that *oblique* form of the anticlinal arch, which we find to be its normal configuration; or how could it give rise to the regular *horizontal bending of the axis-line*, as seen in the curving districts of the chain. Again, in what way can it explain the occurrence of the great lines of fault only on the northwestern side of the axes, or the close oblique foldings, in all the southeastern side of the belt. But, apart from all these objections, on what principle or analogy are we entitled to assume, that the supposed successive shifting of the upward force *would be* in parallel lines. Should the elevation theory be modified so as to suppose the upward force to have been exerted simultaneously along all the present anticlinal lines, but not in the manner of an undulation, the equally formidable difficulty arises of accounting for the production of *any* flexures; since, by the close contiguity of the parallel lines of upward pressure, the sole effect would be a nearly uniform diffused bulging of all that portion of the crust, upon which the tension was exercised.

Of the Origin of the supposed Subterranean Undulations, and of the Manner in which the Strata became permanently bent and dislocated.

The parallel flexures of the crust, so strikingly exhibited in the Appalachian chain, and recognizable, we believe, in nearly all disturbed mountainous districts, we conceive to have originated in the following manner. We assume, that in every region, where a system of flexures prevails, the crust previously rested on a widely extended surface of fluid lava. Let it be supposed, that subterranean causes competent to produce the result, such, for example, as the accumulation of a vast body of elastic vapors and gases, subjected the disturbed portion of the belt to an excessive upward tension, causing it to give way, at successive times, in a series of long parallel rents. By the sudden and explosive escape of the gaseous matter, the prodigious pressure, previously exerted on the surface of the fluid within, being instantly withdrawn, this would rise along the whole line of fissure in the manner of an enormous billow, and suddenly lift with it the overlying flexible crust. Gravity, now operating on the disturbed lava mass, would engender a violent undulation of its whole contiguous surface, so that wave would succeed wave in regular and parallel order, flattening and expanding as they advanced, and imparting a corresponding billowy motion to the overlying strata. Simultaneously with each epoch of oscillation, while the whole crust was thus thrown into parallel flexures, we suppose the undulating tract to have been shoved bodily forward, and secured in its new position by the permanent intrusion, into the rent and dislocated region behind, of the liquid matter injected by the same forces that gave origin to the waves. This forward thrust, operating upon the flexures formed by the waves, would steepen the advanced side of each wave, precisely as the wind, acting on the billows of the ocean, forces forward their crests, and imparts a steeper slope to their leeward sides. A repetition of these forces, by augmenting the inclination on the front of every wave, would result, finally, in the folded structure, with inversion, in all the parts of the belt adjacent to the region of principal disturbance. Here, an increased amount of plication would be caused, not only by the superior violence of the forward horizontal force, but by the production in this district of many lesser groups of waves, interposed between the larger ones, and not endowed with sufficient momentum to reach the remoter sides of the belt. To this interpolation we attribute, in part, the crowded condition of the axes on the side of the undulated district, which borders the region where the rents and dykes occur, and to it we trace the far greater variety which there occurs in the size of the flexures.

In the progress of this bending and folding of the strata, throughout the undulated district, the continual introduction and consolidation in the fissured district, of fresh materials from the liquid mass beneath, rising in intrusive dykes, and filling the wide interstices of the broken strata, would permanently retain the inflected crust in the new attitudes into which it had been forced, and compensate for the reduction of horizontal breadth arising from the flexures. Permanent axes might even be produced without the fracturing of the crust being in all cases apparent at the surface, since innumerable fissures, of sufficient size to permit the sudden escape of an enormous quantity of elastic vapor, could temporarily form, and yet close again superficially, and still the strata be braced and retained in their flexured state by the dislodgement of fragments, and the intrusion and congelation of much lava matter in the lower parts of the rents.

This theory agrees strikingly with the singularly undisturbed condition of the strata, northwest of our great lines of fault. When describing, under a preceding head, some of these enormous dislocations, especially those of southwestern Virginia, an account was given of the gradual transition of structure, from the normal to the folded or inverted form, and thence, to a successive ingulfing of certain groups of strata, into a line of fault, presenting sometimes, for the distance of seventy miles, an actual inversion of the lower Appalachian limestone or slate, upon either the carboniferous limestone or the next inferior group. The commencement in all cases of these faults, in the steeply folded synclinal part of the flexure, immediately on the northwest of the finally inverted anticlinal curve, would seem to prove conclusively, that the fracture has been due to a profound folding in and inversion of the rocks, carried to the extent of producing an actual snapping asunder of the beds where most incurved, followed by a squeezing downward of the opposite side of the trough, by the horizontal northwestward thrust of the anticlinal portion, causing the lower strata of the latter to lie directly upon geologically higher groups. The enormous mass of rocky material, thus forcibly pressed down and firmly held there, would, we conceive, constitute a vast *subterranean barrier or dam*, capable of arresting, in some degree, the progress of the succeeding waves, and of protecting the region for a moderate distance, towards the northwest, or the leeward side of the fault, from the undulations to which it would otherwise have been exposed. In confirmation of this view, it may be stated, that in tracing a line of dislocation toward either extremity, while the extent of strata thrust down, as indicated by the amount of the hiatus at the fault, is inferred to grow progressively less and less, or, what is the same thing, the supposed subterranean dam, presumed to diminish in depth, the region behind it, on the northwest, becomes more and more undulated, until, when we pass beyond the extremity of the fault, to where the normal form of the flexure is restored, we find the strata to the northwest reared into bold anticlinal and synclinal curves. Such is remarkably the fact with the fault at the northwest base of the Peters's and East river mountain, in Virginia, as well as with that which lies parallel to, and southeast of, the Cumberland mountain; and, in a word, with all the faults and crushed axes of great length throughout Virginia, Pennsylvania, and Tennessee. Even where two such lines of dislocation occur, parallel to each other, at an interval of not more than eight or ten miles, the central parts of the intervening tract exhibit unusually little disturbance, notwithstanding their proximity to the lines of violent disruption on each side.

The assumed combination of the wave-like oscillation, and horizontal or tangential movement, will explain, we believe, all those general structural phenomena, which we have described as characterizing our Appalachian chain in all its length and breadth, and which obviously exist in many other mountain chains possessing numerous axes. It will account for all the varieties of flexure, normal, inverted, or dislocated, which are any where observable in the chain, since a mere difference in the ratio of the tangential to the undulatory movement, would produce every grade and form of inflection we have had to record.

The theory explains, moreover, the remarkable law of diminishing steepness in the flexures, as we cross the whole belt northwestward from the region of intrusive veins and dykes, which has evidently been the quarter of extensive and violent actual disruptions of the crust. It moreover affords a reason for the striking parallelism which prevails between the axes in every division of the chain, and the veins and dykes in the corresponding tracts to the southeast. In this rent and dislocated zone of country, beginning with the chain of the Blue ridge, the incalculably numerous and greatly extended dykes and veins that every where penetrate and fill the altered and hypogene rocks, comprise, we believe, an ample quantity of inwedged material, to balance the horizontal contraction of the whole plicated chain.

The mere fact of a regular gradation in the amount of flexure, is of itself a proof, that the axes thus related had a common source, while the direction of this gradation, clearly establishes, that the southeast was the quarter from whence the movement proceeded.

The views here entertained of the nature of the elevating action, afford a satisfactory cause for the arrangement of the axes in groups, since we have merely to imagine successive sets of pulsations of varying magnitude and momentum, to have followed each other in the same general period of disturbance, and we are supplied with a cause sufficient to produce all the diversity which we behold in the distances and directions of the flexures. The almost exact parallelism of these in each group, and the general parallelism of all that enter into the same division of the chain, are the necessary results of that wave-like movement in which we conceive the axes to have originated; and we confess ourselves at a loss to imagine how any other action, but an undulation of the crust, propagated in parallel lines, either straight or curving, could give rise to this extraordinary feature in these enormously extended anticlinal and synclinal lines.

The curious facts connected with the curving form of the axes, in certain districts, are likewise well accounted for by the hypothesis. Of those divisions where they are *convex to the northwest*, and where the curvature is generally so regular, we have merely to suppose that the disturbance began with the production of the axes of each adjoining division, that these terminated towards each other in an obtuse angle, but did not meet; and that, in the angle between them, there was afterwards formed another intermediate belt of undulations. The extremities of these last waves, encountering the flexures already formed in the adjoining straight belts, would be obstructed and retarded in their progress northwestward; but the middle portion of each billow, moving in a tract as yet free from permanent axes, would meet with less impediment, and advance with a higher velocity, so as to impart to the whole of each axis a curvelinear form. It appears, moreover, highly probable, that the fractures of the crust in the dislocated district in the southeast, would themselves be more or less curvilinear in the vicinity of previously formed rents approaching each other at an obtuse angle, and thus a tendency to that shape might be primarily impressed on all the undulations taking their origin in a region so circumstanced.

On the other hand, in those sections of the chain where the axes have a *concave curvature northwestward*, and where there usually exists less regularity in their sweep than in the convex groups, we may imagine that the lines of elevation of the two adjacent straight belts, terminating nearer and nearer to each other, as the axes receded towards the northwest, would soon mutually interfere, and the undulations originating at the southeast, in the space opposite the angle, would find their progress northwestward more and more impeded, as they advanced through the narrowing area between the ends of the flexures previously formed. By unequal and multiplied obstructions thus occasioned, the regularity of the axes in the intermediate division would be greatly impaired.

There is a curious arrangement in échellon, which we notice in many of the groups of axes of the Delaware river or New Jersey division, where, though individually nearly straight, they change their strike more and more to the north as we advance northeastward. This admits of a simple explanation, if we merely suppose a portion of the flexures in the next straight belt on the southwest to have been first produced, and these to have been followed by those on the northeast, which occupy New Jersey and the contiguous districts of New York, the undulations starting as usual from the southeast. The latter, originating last, with a more northern strike, would *converge* upon the former as the waves advance northwestward, and coming in contact with the eastern extremities of the previous flexures, would encounter a retardation at their southwestern ends, while their remote or northeastern extremities would be free to advance with their whole velocity. The natural tendency of this species of resistance, would be to *break* the retarded wave, and to give the northeastern portions a more northerly strike. The whole movement may be likened to the march of a platoon of soldiers in what is called a right oblique order, wherein the advanced files slightly wheel upon the left.

The hypothesis we have advanced, seems also to explain the important fact, that the whole undulated surface, estimated by the average change of level of any given stratum traced across the chain, rises in a regularly inclined plane southeastward, or towards the quarter where we find, by other evidence, that the uplifting and undulating action was most powerful. This circumstance, of a progressive rise of the whole belt towards the side which anciently lay near the shore of the Appalachian ocean, accords entirely with the belief, that under the now rent and dislocated margin of the chain, there was a vast accumulation of fluid rock, charged with compressed gaseous matter, which exerted on the crust an enormous disrupting tension.

On the Identity of the Undulations which produced the Axes, with the wave-like Motion of the Earth in Earthquakes.

That the undulatory movements which we suppose to have been the primary cause of our Appalachian axes, and generally of all other parallel flexures, were strictly analogous to well-known phenomena of the present day, is apparent, when we examine the nature of that tremendous agitation of the crust, which we call an earthquake. A *wave-like* undulation of the ground is of such common occurrence during great earthquakes, that we are inclined to consider it as their essential condition. On this subject, we possess the concurrent testimony of the best observers and historians of these events, particularly Michell, Dolomieu, Lyell, and Darwin. Michell, writing on the subject of "The Cause and Phenomena of Earthquakes," in the Philosophical Transactions for 1760, says, that the motion of the earth is partly tremulous, and partly propagated by waves, which succeed one another at larger and smaller distances, the undulation extending much further than the tremor. At Jamaica, in 1687–8, a gentleman saw the ground rise, like the sea, in a wave, as the earthquake passed along, and he could distinguish the effects for some miles, by the waving of the tree-tops on the hills. The same was witnessed in New England, November 18th, 1755. The wave-like motion of the great Lisbon earthquake, which happened on the first of November, 1755, was perceived by the motion of water, and the hanging branches in churches through all Germany, amongst the Alps, in Denmark, Sweden, Norway, and all over the British islands. This tremendous movement even reached the West Indies, a distance from the seat of principal violence, of nearly three thousand miles. A comparison of the times at which the first shock was felt at Lisbon and at other places, shows the undulation to have travelled at the rate of more than *twenty miles per minute.*

Dolomieu, in his dissertation on the great Calabrian earthquake, states, according to Mr. Lyell, that "the surface of the country often heaved like the billows of a swelling sea, which produced a swimming in the head like sea-sickness," and he further mentions as "a well-known fact, that the trees sometimes bent during the shocks to the earth, and touched it with their tops."* This rocking motion of the surface was likewise experienced by Darwin, in South America, who states, on the authority of Acasto, that the earthquakes of that country extend three hundred, six hundred, nine hundred, and some of them even one thousand five hundred miles along the coast.†

That this motion is of the nature of an actual billowy oscillation of the crust, is likewise plainly indicated by the attendant

* See Lyell's Principles, Boston edition, vol. 2. p. 330.

† See a paper by Darwin, in Transactions of Geological Society of London

phenomena, especially by the uniformity in the direction which the earthquake takes, and by the opening of great chasms and fissures in the ground, parallel to each other, and perpendicular to the course of the shock or undulation. Thus it is recorded, that, during the earthquake that shook the valley of the Mississippi, in 1811, the inhabitants felt the earth rise in great undulations, and that the ground opened in numerous parallel fissures, having a direction from northeast to southwest. This close correspondence between the direction of the cracks, and that which invariably characterizes our Appalachian axes or faults, is a remarkable circumstance, that well demands the attention of geologists. It lends a further probability to our hypothesis, which merely imagines a very much more energetic series of undulations to have occurred during the elevation of all this part of the continent. There is reason to think that this agreement in the direction of the forces at periods so remote, is not merely casual; for it appears, from a statement of Michell, that of five considerable earthquakes, felt in New England before his time, three are known to have come from the northwest, and the other two are supposed to have had the same direction. Recent observations in Scotland indicate that the earthquake which was there felt in October, 1839, consisted of undulations moving from northwest to southeast, or in a direction perpendicular to the strike of all the older axes of that country.

Of the manner in which the wave-like movements in earthquakes may be supposed to originate, Michell suggests, that large tracts of country may rest on fluid lava, which, when disturbed, may transmit its motion through the overlying crust; but he offers the following as the explanation of the mode in which the undulations may take place. "Suppose a large cloth, or a carpet, spread upon a floor, to be raised at one edge, and then suddenly brought down again to the floor; the air under it being by this means propelled, will pass along, till it escapes at the opposite side, raising the cloth in a wave all the way as it goes. In like manner, a large quantity of vapor may be conceived to raise the earth in a wave, as it passes along between the strata, which it may easily separate in a horizontal direction, there being little or no cohesion between one stratum and another. The part of the earth that is first raised, being bent from its natural form, will endeavor to restore itself by its elasticity, and the parts next to it being to have their weight supported by the vapor which will insinuate itself under them, will be raised in their turn, till it either finds some vent, or is again condensed by the cold into water, and by that means prevented from proceeding any further."*

Now we conceive that there is a simpler view of the origin of the undulation, and one which is more in accordance with sound dynamical considerations, and with all the recorded observations upon earthquakes. In place of supposing it possible for a body of vapor or gaseous matter to pass horizontally between the strata, or even between the crust and the fluid lava upon which it floats, and with which it must be closely entangled, we are inclined to attribute the movement to an *actual pulsation*, engendered in the *molten matter itself*, by a linear disruption under enormous tension, giving vent, explosively, to elastic vapors, escaping either to the surface, or into cavernous spaces beneath. According to this supposition, the movement of the subterranean vapors would be *towards*, and not from the disrupted belt, and the oscillation of the crust would originate in the tremendous and sudden disturbance of the previous pressure on the surface of the lava mass below, brought about by the instantaneous and violent rending of the overlying strata.

It has been denied by some — and the objection seems to be acceded to by Mr. Lyell — that the so-called wave-like motion of the surface in earthquakes, has "any strict analogy with the undulations of a fluid." On the other hand, "it has been suggested, that a vibratory jar may be produced at a considerable depth, by a sudden fracture of the solid crust, and that the vibrations may be propagated upward through a mass of rock, even several miles thick. The first vibration which reaches the surface will lift the soil, and then allow it to sink again; immediately after which another, which may have radiated from the same deep-seated point, may arrive at a contiguous spot on the surface, and cause

* Michell, Phil. Transactions, 1760.

a similar rise and fall, and so others in succession, giving rise to a progressive motion of the ground, very similar in appearance to a wave of the sea."*

To the suggestion of a propagated vibrating jar being the cause of the rocking of the surface, we will reply by simply referring to all the authentic accounts of earthquakes, in which the regularly progressive march of the billowy undulation is so frequently described by eye-witnesses, and likewise to the statements of Michell, who gives, from abundant data, the *very rate* of the passage of the great Lisbon earthquake, across an area exceeding three thousand miles in breadth. As regards the other supposed difficulty, that the radius of each superficial curvature must be very small, we contend that this is by no means a necessary inference from the phenomena, since if we take into consideration the prodigiously high velocity with which earthquakes seem to move, we find a reason at once, why tall objects, like trees, may rock from side to side with a rapid oscillation, while the wave which disturbs them may possess an enormous breadth. A low and broad wave, if moving slowly, would only tilt the objects under which it might pass, into attitudes perpendicular to its gentle slopes, but the lowest and broadest billow, passing with the amazing speed of the Lisbon earthquake, might, by suddenly shoving the foundations or pedestals of objects from beneath them, and as suddenly pushing them in the opposite direction, cause them to swing rapidly through arcs of almost any extent.

While the evidence, therefore, seems ample, of the existence of a wave-like motion of the earth's surface during earthquakes, facts are not wanting which indicate the recent production, from this cause, of permanent anticlinal axes. Thus we find, in Darwin's Journal of Travels in South America, the following interesting statement. Mr. Gill, an engineer, mentioned to that intelligent traveller, that following up the bed of a stream, strewed with sand and gravel, and showing in one place, a channel in the solid rock about forty yards wide, and eight feet deep, he found himself suddenly going *down* hill, the whole descent amounting to forty

* Lyell's Principles, Boston edition, vol. 11.

or fifty feet of change of level. Here there was a decided arching of the surface, by which the river had been displaced from its ancient valley. Occurring in Chili, in a country so frequently visited by earthquakes, there can be little doubt as to the origin of this local anticlinal flexure in the earth's crust.

We are inclined to regard the Ullah Bund as another example of an anticlinal axis formed in modern times by an earthquake. According to the description and map furnished by Mr. Lyell, in his admirable account of earthquakes contained in his Principles, this is a long elevated mound, extending from east to west across the eastern arm of the Indus, near the fort and village of Sindree. It is upwards of *fifty miles in length*, and runs parallel to a line of *subsidence*, along which the previously low and perfectly level plain around Sindree became permanently flooded. It is conjectured to be, in some parts, sixteen miles in width, and to have a height above the original level of the delta, of ten feet, which it seems to preserve very uniformly.

Of the Date of the Appalachian Axes.

It has been stated already, that, excepting in one or two localities, the Appalachian formations constitute an unbroken succession of conforming strata, from the lowest members of the system, which repose immediately on the primary or metamorphic rocks, to the highest of the carboniferous strata. We must therefore conclude, that the elevatory actions, which lifted the entire chain above the level of the ancient sea, and impressed upon it those symmetrical features of structure which we have described, could not have begun, at least with any degree of intensity, until the completion of the carboniferous formation. That the principal movement *immediately* succeeded the termination of this period of gradual operations, or more properly arrested the further progress of the coal-formation, is, we think, clearly proved, by the fact, that nowhere do we meet with any strata, referable to the next succeeding or new red sandstone period, overlying the highest rocks appertaining to the coal; and it can scarcely be supposed, that throughout so vast an area, embracing several enormous basins, in which the upper carboniferous rocks have been preserved, all traces of that newer group, if deposited, should have been so entirely swept away, as not to have left its fragments even in any part of the wide tracts over which the coal-rocks are spread. An additional reason for believing that the elevation and flexure of the strata did not take place as late as the era of the new red sandstone, is to be found in the remarkably undisturbed manner in which a set of rocks of the age, approximately at least, of the European new red group, rest unconformably on the axes which traverse the Appalachian formations. All the geological relations of these overlying rocks, occupying a very prolonged belt to the southeast of all the carboniferous strata, but especially those of their organic remains, would seem to ally them closely to the New red sandstone group of Europe, and probably to its newest division. Extending almost continuously in a narrow belt from the valley of the Connecticut, to beyond the southern boundary of Virginia, these strata neither contain any axes of elevation, nor do they exhibit even a conformity of strike with the neighboring Appalachian and metamorphic rocks; and, although they repose, throughout a great part of the belt, immediately on the folded and inverted older strata, they furnish not the slightest indication of having been disturbed by the movements which produced the numerous axes beneath. We may hence confidently infer, that the great undulations which elevated those older formations, from the metamorphic to the carboniferous rocks inclusively, were antecedent to the deposition of these newer beds, and therefore that the age of the axes has been correctly determined to be antecedent to the commencement of the new red sandstone period.

That few or none of the principal Appalachian axes originated before the last of the coal strata were deposited, is demonstrably proved by the almost universal conformity or parallelism of all the strata. It is only necessary to consult the several sections appended to this paper, to recognize the important fact, that from the earliest to the latest of these Palæozoic rocks, extending probably somewhat further back than the Silurian formations of Europe,* and terminating with the last layers of the coal, no per-

* See a paper by Conrad, in Journal Academy of Natural Science, vol. 8, part 21.

manent flexures or other disturbances of the crust occurred, to interrupt this continuous and amazingly prolonged succession of parallel deposits.

In thus confining the era of the principal movement which elevated the Appalachian chain to a comparatively short period, at the very close of the carboniferous formation, we are far from implying that a few local elevations, and many minor oscillations of the surface, unattended by permanent flexures, did not occur previously to this final, and, beyond all comparison, most energetic effort of the subterranean forces. The unconformable superposition locally, of the Helderberg strata, upon the Hudson river slates, in the vicinity of the town of Hudson, is a sufficient evidence that even at an early period in the history of the Appalachian formations, this part of the region was disturbed by a *considerable movement* of the strata already deposited; and there are indications that similar agitations of the Appalachian territory, but to a much feebler extent, were experienced at the same and at other periods, during the progress of these formations. But, with the single local exception spoken of, none of these disturbances appear to have interrupted, however partially, the perfect general conformity of the strata throughout the whole Appalachian system. The occurrence of *feeble* movements, from time to time, in the earlier ages of the long Appalachian period, is clearly proved by the presence of fragments of older strata, enclosed in the next succeeding beds, and also by the coarseness of the materials of which some of the formations largely consist. The phenomena of the coal-measures, at the same time, go to show, as one of us has attempted to argue in another paper, that these movements continued to increase in frequency and power, as the Appalachian period drew near its termination; the entire coal-formation being the result of alternate quiet accumulations, and sudden paroxysmal movements, terminating in that stupendous train of actions, which lifted the whole Appalachian chain from the bed of the ancient sea.

The obvious agreement in point of date, between this, which was incomparably the most energetic and extensive change in the physical structure of North America, and the wide-spread revolution, which raised the European coal strata from the aqueous bed in which they were deposited, is a result of the highest interest in the comparative geology of the two continents. It would seem that the movement which produced so general and sudden a cessation to the progress of the coal strata, led to grander changes in the earth's surface than any disturbance since. Those displacements of land and sea, which severally terminated the Silurian and Devonian systems in Northern Europe, great as they truly appear, were, after all, but *local* events; not extending, except in their indirect consequences, to the distant Appalachian shores, and, it would seem, hardly to the oceanic tracts of the European basin in Russia. Over *how wide* a limit these movements were decidedly influential in the *organic* world, must soon become a problem of the highest interest to our science.

Analogous Phenomena of Axes in other Countries.

A perception of the important and novel bearings of the curious laws of structure here described, upon many points in geological dynamics, has led us to examine, with deep interest, the valuable and accurate labors of Fitton, Martin, De la Beche, Dumont, Murchison, Sedgewick, Weaver, Hopkins, and other eminent European geologists, in the expectation of finding in the phenomena they describe, evidences of analogous laws.

While studying, with this view, such memoirs, sections, and maps as were within our reach, we have enjoyed no small gratification in discovering, what we consider numerous striking proofs of the prevalence of similar structural features in some of the most interesting geological regions in Great Britain and on the continent.

Among these we would first mention the peculiarly interesting districts of Wales, to which the admirable researches of Messrs. Sedgewick and Murchison have, of late years, imparted so high a geological importance. In the beautiful and elaborate work of the latter geologist, the publication of which forms one of the great eras in geological science, we think we discern very distinct proofs that the Cambrian and Silurian axes of Wales, possess similar structural features with those of our Appalachian chain. While the older strata of the Berwyn mountains, as described by Mr. Murchison (Silurian System), would seem, by their altered character, and frequently inverted dips, to mark a close proximity to one of the great lines of disturbance of the district, that lying towards the northwest, from which has been propagated a combined uplifting and tangential force; the contour of the undulations, lying more towards the southeast, when unaffected by faults or local disrupting action, exhibits a general conformity to our law of a steepening flexure, on the side towards which the movement has proceeded. As illustrations of this law, we would beg to refer the reader to a few of the beautiful sections appended to Mr. Murchison's work on the Silurian System.

First. Plate 31, fig. 5. Section across the Ludlow and Brecon anticlinal, exposing the valley of elevation of Wigmore lake.

Second. Plate 34, fig. 3. This exhibits, to the northwest, the lower Silurian *on end*, for some distance from its contact with the Cambrian, after which it passes by a bold sigmoid flexure, in which the southeast dips are *very steep*, beneath the upper Silurian.

Third. Plate 34, fig. 7. Shows, on the northwest, *inverted flexures or foldings*, in the Llandeilo flags, then steep southeast dipping Caradoc sandstone, and, following this, the Upper Silurian and the Old red, with gradually diminishing dips. Fig. 8, of the same plate, presents analogous phenomena, though they are less distinct.

Fourth. Plate 34, fig. 9. Displays an *inverted* and *folded flexure*, succeeded by steep southeast dips, in the flagstones of the Cambrian, following which are two *normal arches* in the lower Silurian.

To these Sections may be added the Vignette, page 359, presenting an axis in the Cambrian rocks of Caermarthenshire.

In the eastern portion of this district, bordering the Malvern hills, the flexures would appear to be related, according to the same law, to the great line of elevating action, extending in a north and south direction through that region. The *steeper* sides of the arches are now towards the *west*, and the lower rocks are often overturned, so as to dip towards the east, thus exhibiting a direction of flexure, nearly opposite to that of the strata near the Berwyn chain. As examples of these phenomena, we would refer to Plate 36, fig. 8, presenting a transverse section of the Malvern and Sedbury hills, and figs. 9, 9[b], 10, of the same plate, exhibiting the structure of the Woolhope axis.

The same general structural features, will, we confidently believe, be found to prevail in the perplexing stratification of those parts of Devonshire and Cornwall, which, of late years, have drawn out much earnest theoretical discussion among British geologists. An inspection of the sections accompanying Sir H. De la Beche's elaborate Report, those, for example, from Combemartin to Bolt-hill, and from Linton to Bideford, and a careful examination of the descriptions of this region, given by him in that work, and by Messrs. Sedgewick and Murchison, in their very able memoir " On the Physical Structure and older Deposits of Devonshire," induces us to venture the prediction, that, throughout the region to which they refer, the phenomena of folded axes will be found of very extensive occurrence, and that this folding and inversion, together with the general law of steepening flexure in a particular direction, will explain the frequent repetitions of certain groups of strata, and assist in removing much of the obscurity that still hangs round the intricate geology of some parts of that district.

Similar indications are, we think, presented in the structure of the southern and southeastern parts of Ireland, as described by Weaver, Griffith, Hamilton, and Austin. Among these may be instanced *the great predominance of southern dips*, those to the north being only occasional and of short continuance; a result, in our view, naturally arising from a succession of folded and steeply normal flexures, due to a pulsatory movement propagated from the south. The evidences of such foldings and inversions, are, we think, quite observable, in the account given by Mr. Weaver, of the parallel bands and patches, in échellon, of the older limestones, while the steepened dip, and extensive folding and inversion among the higher rocks, resulting from the same forces, are strongly implied in the section given by the same author, through the Dromagh coal-field.* Similar phenomena would seem to be referred to, also, by Mr. Austin, when, in speaking of the neighborhood of Waterford, he ascribes the numerous contortions of schistose rocks, considered by him as being of the age of the Silurian, to *excessive lateral pressure*.†

From the delineations and descriptions of the structure of the Alps, and more particularly of the Jura, which we have met with, we are led to believe that precisely similar structural features prevail in those disturbed chains. The various sections, illustrative of M. Thurman's work, 'Essai sur les Soulevemens Jurassiques,' may be appealed to as furnishing conclusive proof, that the axis-planes of the numerous parallel anticlinal and synclinal axes of the Jura, are in every case *oblique*, and that they dip, in a great majority of instances, south-southeast, or towards the Alps.

Belgium, and the Rhenish provinces, seem to exhibit features of structure strikingly analagous to those of our Appalachian chain; and we think we do not go too far, when we affirm, that in those "extraordinary derangements and disturbances," and those "almost incredible phenomena of dislocation, contortion, and inversion," referred to by Dr. Buckland, as having been so ably elucidated by M. Dumont, we clearly recognize some of the general laws described in this paper, and made familiar by our researches in the Appalachian belt. On this head we would refer to the observations of Messrs. Murchison and Sedgewick, contained in their memoir "On the Classification and Distribution of the Older Rocks of Germany," of which an abstract is published in the Proceedings of the Geological Society of London. These distinguished geologists, when speaking of the groups of strata beneath the lower Westphalian limestone, thus describe the structure of the region northwest of the chain of the Taunus. "For many miles south of the undisturbed range of the lower Westphalia limestone, the prevailing dip is about north-northwest; the country round Seigen is regarded as a kind of dome of elevation,

* See Memoir on the Geological Relations of the South of Ireland, by Thomas Weaver, Esq. Trans. Geol. Soc. Lond., 2d series, vol. V.

† See Proceedings of the Geol. Soc., Lond., No. 74.

composed of the lower part of this series; for, still further south, the dip is *reversed* to the south-southeast, and in a traverse from Seigen to the Taunus, across the strike, (a distance of about fifty miles,) the same dip is continued, with very few interruptions. Considering their high inclination, this fact seems to give an almost incredible thickness to the deposits in question. But the vertical sections do not give the order of superposition, for at Dillenburg, and on the Lahn, *two great Devonian troughs* are brought in among the older strata, *without any general change of dip;* and if we accepted the vertical sections as the sole proofs of superposition, we must place the Devonian, and a part of the carboniferous series, under the chain of the Taunus."

If we are correct in our interpretation of the phenomena here described, they present an instance of structure which is of frequent occurrence in the Appalachian belt, where the rocks of the southeastern portion of a synclinal flexure, are folded over into southeastern or inverted dips, or where the axis-planes of both anticlinal and synclinal flexures are inclined very obliquely to the horizon, dipping in parallel directions to the southeast. The chain of the Hundsruck, and its continuation, the Taunus, of which they regard the Quartzite and Chlorite slates as "but altered forms of a great Silurian group, under the Eifel limestone," would thus appear to occupy a similar position to that of some of the ridges on the southeastern margin of the Appalachian region, where we meet with very similar phenomena of alteration, accompanied by a large amount of intrusive matter, and adjacent to this, on the northwest, many inversions and foldings of the strata. Including, in one view, the portions of Belgium, the Rhenish provinces, the Westphalian coal-field, and the Hundsruck, Taunus, and Hartz ranges, described by those geologists as displaying an extended series of Cambrian, Silurian, and Devonian strata, we are strongly of opinion, that the relations of dip which they present, will be found reducible, in great part, to the laws of structure we have endeavored to develope, and fairly referable to a similar undulatory movement directed towards the northwest.

From the observations of Dr. Fitton, on the structure of the Wealden and associated formations, as detailed in his admirable memoir on the Strata below the Chalk, and likewise from the more recent investigations, in the same region, by Mr. Hopkins, of which a summary is to be seen in the proceedings of the Geological Society of London, for 1841, it would appear, that in the districts of the Wealden and Bas Boulonnais, the numerous axes observe a *curved* form, and are nevertheless *parallel* to one another. Mr. Hopkins, after describing several of these flexures, states, that "all these lines preserve a remarkable parallelism with each other, and with the curved central axis of the district." It would further appear, from the observations of these distinguished geologists, unless we have given an erroneous interpretation to their sections and descriptions, that a great number, if not all of these axes, present a much steeper dip on one side than on the other, and that this stronger inflection generally occurs on the same, to wit, the *northern side.* Speaking of the line from Farnham to Seven-oaks, Mr. Hopkins uses these words: "It is a line of flexure,* with a great dip to the north, but without the corresponding dip to the south, necessary to form an anticlinal arrangement, except in one or two localities. Towards the west, it runs immediately at the foot of the hogsback, with a dip, which, near its western extremity, amounts to seventy or eighty degrees." "Tracing it towards the east," he adds, that, "at some points the line assumes a distinct anticlinal character.

Dr. Fitton, in describing the interior of Kent (p. 134 and 135), gives several drawings of sections of this or an adjoining axis, in all of which the predominance of the dip on the northern side is distinctly marked. Alluding to one of these sections, he says: "Both sides of the saddle are visible within a few paces; the beds on the north rising at an angle of about sixty degrees, while on the south, they decline at an angle of forty-five degrees." As illustrating the same law, we would more particularly refer to the following colored sections, appended to Dr. Fitton's memoir.

* By the term flexure, as explained by the phrase, *one-sided saddles*, used in the same connection, we infer the author to mean, what we denominate, *oblique flexures*, while he restricts the term anticlinal, to those bendings which give, approximately, equal dips on the opposite sides.

First. The section across the Weald, from the South Downs, Western Sussex, to the Surrey hills. In this, the dip, on the northern side of the great axis, is represented as slightly greater than on the southern side.

Second. The two combined sections, along the southeastern and southwestern coasts of the Isle of Wight. The axis traversing this island, and continued to Purbeck, is represented on the map accompanying the memoir of Dr. F., as parallel with that of the Weald. The sections referred to cross this axis, and exhibit a much greater steepness of dip on the northern than the southern side.

Third. The three sections across the vale of Wardour, transverse to the axis of that region. In all of these, the preponderance of dip on the northern side is very great.

This series of curved or undulating axes, which are, in the main, parallel to each other, would thus appear to manifest laws of structure, strictly analogous to those of our Appalachian region; and they serve still further to confirm us in our belief of the prevalence of similar features, among the flexures, in all regions of extensive disturbance, as well as to increase our reliance on the justness of the theoretical views by which we have attempted to explain them.

In conclusion, we would express our belief, founded on the phenomena referred to in this memoir, and on numerous similar geological facts, of recent as well as ancient date, which cannot be mentioned in this place, that all great *paroxysmal actions*, from the earliest epochs, to the present time, have been accompanied by a *wave-like motion of the earth's crust.*

Observations of Subterranean Temperature in the Coal-Mines of Eastern Virginia. By Wm. B. Rogers, *Professor of Natural Philosophy in the University of Virginia.*

The important law of an augmenting temperature as we descend to considerable depths beneath the surface of the earth, has, it is well known, been amply demonstrated in regard to Europe, by the numerous observations made in the mines and artesian wells of that portion of the globe, but with the single exception of Humboldt's observations in Mexico, no direct recorded proof has yet been furnished of its applicability to the Continent of America. The results detailed in the present communication, forming the first published confirmation of this law as regards any part of the United States will, therefore, it is conceived, be viewed as an important contribution to our knowledge on the subject, and will, it is hoped, conduce to more extended observations of the same description in other parts of our country, where the requisite opportunities exist.

The mines in which these results have been obtained, lie in the most productive part of the Öolite coal-measures of Eastern Virginia, and are of various depths, from 100 to nearly 800 feet. These coal-bearing strata rest upon an irregular basin-shaped floor of sienitic and gneissoid rocks, which forms the lower limit of the workings, and is penetrated for a few feet by some of the deeper shafts, as well as by the shallow ones nearest the margin of the field. They consist in great part of felspathic and micaceous sandstone, the coarser beds of which, formed of the almost unworn materials of the neighboring crystalline rocks compactly reunited, are sometimes scarcely distinguishable from the weathered portions of the parent mass.

The coal, consisting of a single seam, or of two contiguous seams, having an aggregate thickness varying from twenty to fifty feet, lies within a few feet and sometimes a few inches of the undulating floor, separated from it by bituminous slates and shales. Beds of the latter material, abounding in impressions of plants, and in some localities with those of fish, rest directly upon the principal mass of coal, and occupy the interval between the seams, where there are two.

The most common dip is towards the west, often at a very high angle, but owing to original irregularities in the gneissoid floor, and enormous dislocations subsequent to the filling up of the basin, the strike and inclination of the beds are subject to sudden and great transitions.

The open texture, high inclination, and fractured condition of the strata, favoring the descent of streams from above, cause a large influx of water into many of the workings. This forming part of the liquid collected in the wells at the bottom of the principal shafts, prior to its removal by the buckets, imparts as I have always found, a lower temperature to the mass of water there accumulated than is proper to the bottom strata. The small streams flowing from between the surface of the granite and the coal, or from the rocks above the coal, have, on the contrary, always presented a close approximation to the temperature of the strata from which they make their escape. I have therefore, whenever practicable, resorted to such streams, occasionally comparing their temperature with that of the adjoining rocks, by a thermometer, duly inserted in the mass.

Some of the following observations, it will be seen, were made in workings in active operation, and where the heating effects of the workmen, mules, and lamps, might be supposed to have made the results too high. The amount of their influence, however, could not have been considerable, as the temperature was determined by plunging the thermometer into a body of water continually replenished from the rock. Indeed, as will be proved in the sequel, this influence upon the average result was more than compensated by the cooling effect of the drippings from above.

The remaining observations were made in shafts just completed or in progress, and where the chief modifying influence was the cooling agency of the drippings from the higher beds.

I. Observations made in Mines actually or but lately in operation.

1. *At Mill's and Reed's Mine*, called the Creekpit, the temperature was taken at three different levels, by plunging the thermometer for some time into the water collected at the bottom of the main shaft, and the shafts connecting the lower levels. The amount of water accumulated at these points was very considerable, and the liquid was continually drawn off by the engine and replenished from the galleries of the mines. The following were the results:

Depth.	Temperature.
318 feet,	59.° 5
375 "	61.
420 "	63.

2. *Greenhole Pit.* This is one of the comparatively shallow mines at the margin of the field. When the observation was taken there were but few hands employed in it. The temperature observed was that of a collection of water at the bottom of the shaft, about a foot in depth. Result:

Depth.	Temperature.
100 feet,	58.°

3. *Engine Pit belonging to the Black Heth Company.* The air of this mine was obviously a good deal heated when the workings were in active progress, and I therefore selected for my observations a gallery remote from any present operations, and in which no work had been done for some time. The thermometer was immersed in a pool of water about 18 inches deep continually supplied from the neighboring strata. It was afterwards inserted for some time into the rock of the floor, and with the same result, which was—

Depth.	Temperature.
412 feet,	63.°

The temperature of the water at the bottom of the main shaft of this mine was found to be 61.° 5; but in this case it was evident that a large amount of liquid flowed from the upper strata and thus reduced the temperature of the whole.

4. *Wills and Michael's Pit.* The works were in active progress in this mine when the observations were made. The temperature first noted was that of the water at the bottom of the main shaft; the second, that of a similar pool in the lowest level. The results were—

Depth.	Temperature.
386 feet,	62.°
570 "	65. 5

II. Observations made in Shafts either just completed or in progress.

1. *Black Heth New Shaft* (1836). This shaft, which was in progress at the time of my observation, had reached the depth of 380 feet. The water at the bottom, which collected rapidly, was derived in part from the small streams flowing in from the adjacent rock, and partly from that which dripped from the edges of the higher strata. The temperature of the liquid in a small pool was 60°. That of the rock, as shown by a thermometer inserted deeply into a crevice on one side, was 61.° 5. But the free access of moisture and air had no doubt depressed the temperature slightly, even in this position. Upon exposing the bulb to a stream of drops coming from some distance above, it indicated a temperature of 59°. It is therefore evident that the true temperature of the rock, at the bottom of this shaft, is somewhat over 61.° 5.

Depth.	Temperature.
380 feet,	61.°5

2. *Mid Lothian New Shaft* (1839). This shaft, cutting through a seam of coal 36 feet thick, penetrated a coarse grit for a few feet, and then struck into the sienitic floor. Immediately above and beneath the coal, and from the rock in contact

with the sienite, numerous small streams were flowing out into the shaft. In the lowest of these the thermometer was exposed until its temperature became stationary. The following was the accordant result of several such observations:

Depth.	Temperature.
780 feet, ...	68.° 75

3. *Mid Lothian New Shaft* (1842). This shaft, in the same field with the preceding, and near it, had at the time of my observations reached the depth of 600 feet. Near the bottom it passed through a thin seam of coal and coal shale, in all about six feet, and beneath this to the bottom, a distance of about ten feet, it exposed dark argillaceous slates, the main mass of coal not having then been attained.

At a point 330 feet below the top of the shaft, a beautiful and rather bold spring issues from the sandstone, which is conducted downwards by a gutter cut in a spiral form around the shaft. The temperature of this stream, where it first appears, was carefully measured, and found to be 61.° 75. At the bottom, numerous very small streams come in from the rock. These all agreed in giving the temperature 66.° 25, which I therefore infer to be very nearly the temperature of the strata at that depth. The very copious drippings from above, together with the spring before noticed, blending with the infiltration from the strata near the bottom, formed a considerable pool, requiring the active use of the buckets. The temperature of this mixed water I found to be 63.° 5.

At the time of these observations only two hands were at work in the shaft, and there had been no blasting for some time before I descended. I therefore consider the observations on the spring at 330 feet, and the small streams at the bottom, to be as accurate indications of the temperatures at those depths as this or perhaps any other method of examination admits of. We have therefore in this shaft—

Depth.	Temperature.
330 feet, ...	61.° 75
600 "	66.° 25

The former of these results, it will be seen, is slightly above the temperature of the Black Heth new shaft, previously cited, though this shaft was fifty feet deeper. This difference is doubtless owing to the very large amount of cooler water which descended in drippings to the bottom of the Black Heth shaft, causing a decided reduction of temperature in the rock, in which the thermometer was inserted.

Assuming 56.° 75, the mean temperature of Shockoe hill, Richmond, as a sufficiently near approximation to that of the region of these mines, which is only about twelve miles from the city, the following Tables will exhibit the results of my observations, together with the excess of the subterranean temperature, at each depth, over the average heat of the surface.

TABLE I. OBSERVATIONS IN MINES IN OPERATION AT THE TIME.

	Depth.	Temperature.	Excess.
Greenhole Pit,	100 feet,	58°	1.°25
Mills and Reed's Pit,	318 "	59.5	2.75
" " " "	375 "	61.	4.25
" " " "	420 "	63.	6.25
Black Heth Engine,	412 "	63	6.25
Wills and Michael's,	386 "	62	5.25
" " "	570 "	65.5	8.75

TABLE II. OBSERVATIONS IN SHAFTS EITHER JUST COMPLETED OR IN PROGRESS.

	Depth.	Temperature.	Excess.
Black Heth new shaft,	380 feet,	61.°5	4.°75
Mid Lothian (spring),	330 "	61.75	5.00
" " (bottom),	600 "	66.25	9.50
" " (deep),	780 "	68.75	12.00

Making no deduction for the depth of the *invariable* plane, the results embraced in the first table give, as the rate of increase of temperature with the depth, 1° for 74 feet.

Assuming sixty feet for the depth of this plane, a distance which, from the open and moist condition of the rocks, I think more likely to fall below than to exceed the truth, and calculating the ratio of increase beneath this point, I find it to be 1° for 62 feet.

Making like computations in reference to the second table, the results are—

1st. Estimated from the surface down, 1° to 66 feet.

2d. Estimated from the invariable plane down, 1° to 59 feet.

Comparing the numbers deduced from the two classes of observations together, it will be seen that the diminution of temperature in descending is *slower* in the *mines in active operation* than in the recently opened shafts; so that, whatever may be the extraneous heating influences affecting the former, they are more than counterbalanced by the permanent cooling due to the descent into all parts of the mine of the cooler water from above.

Comparing the three last observations in table second, the two former of which were made in the same shaft, and the last in one only a few hundred feet removed, there is ground for inferring that the rate at which the temperature increases grows less as the depth augments. In descending from 330 feet to 600, that is, through 270 feet, the rise of temperature is 4.°5; while in descending from 600 to 780, or through 280 feet, the rise is only 2.°5. This difference would, I think, have been less, could I have obtained the temperature at 780 feet free from the cooling influence of the copious drippings from above. Yet even with the most liberal allowance, there would still remain evidence of a diminishing rate of increase with the depth, such as has already been remarked by Mr. Fox and other European observers.

Considering the observations in the Mid Lothian shaft at 330 and 600 feet, as the ones most exempt from any known source of error, and deducing the rate of increase from them, I find the result to be almost precisely that inferred from table second, that is 1° for every 60 feet.

I may therefore, I think, in conclusion, affirm as approximately true, for the region in which these mines are situated, that from the *invariable plane* downwards for many hundred feet, *the temperature augments at the rate of* 1° *for every* 60 *feet of depth.*

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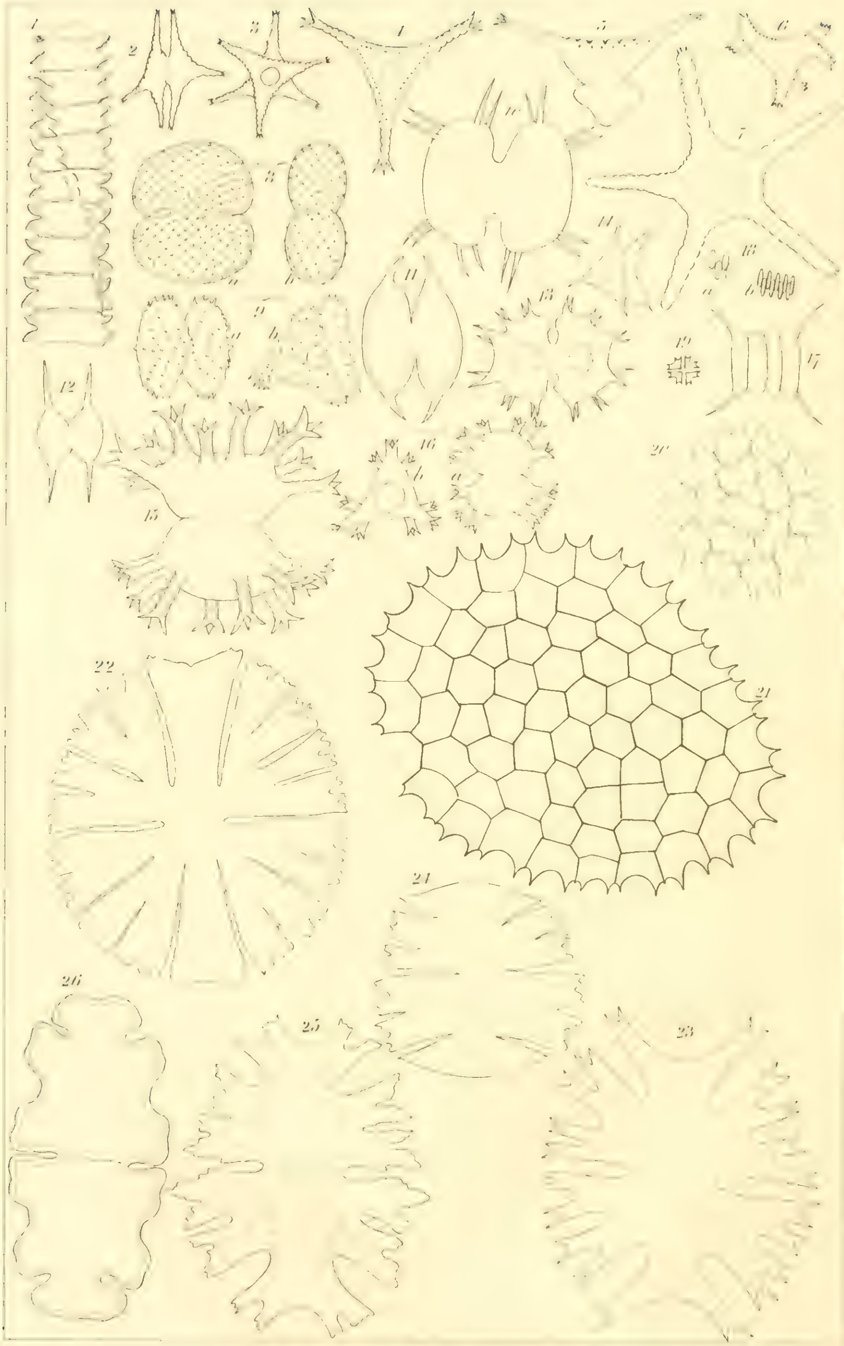
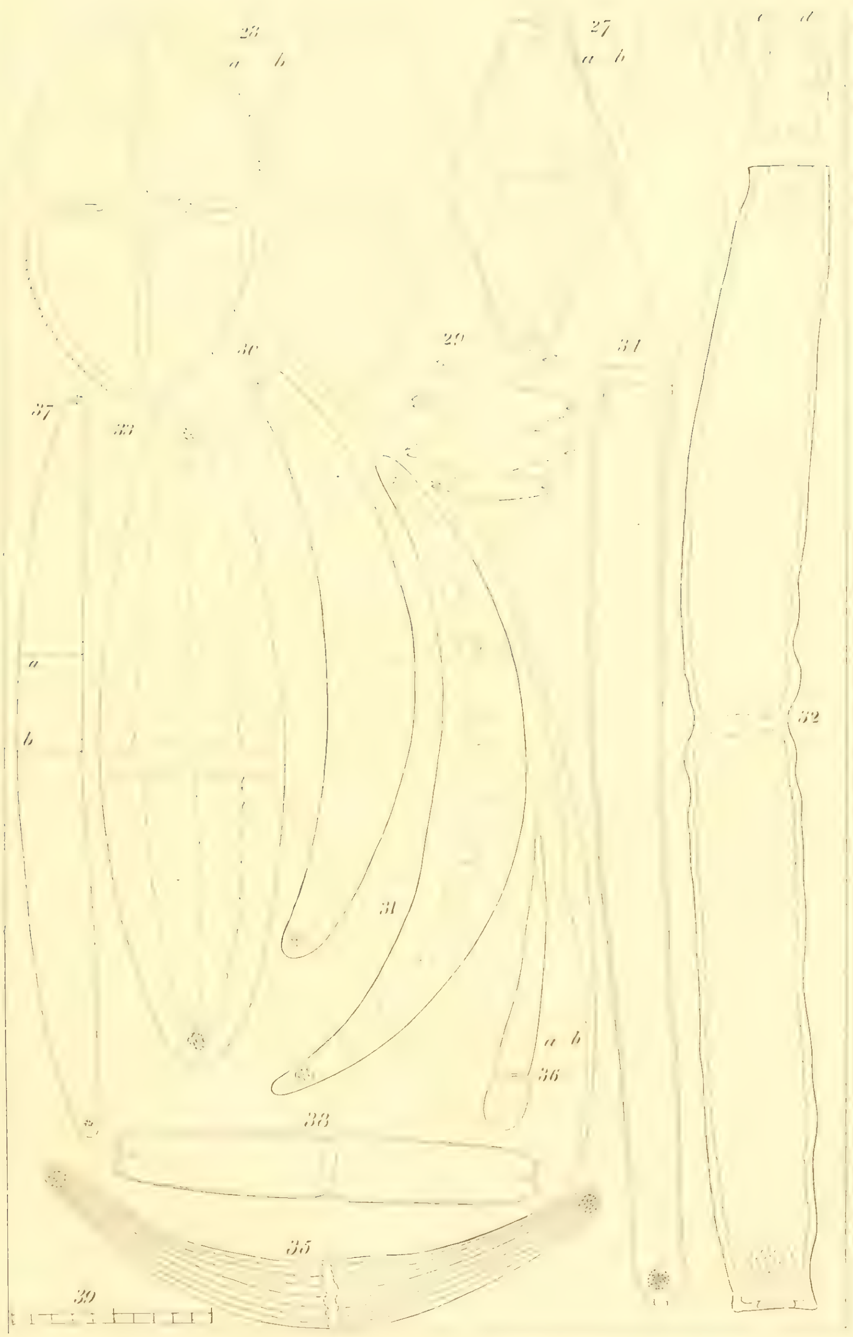


Plate first Part first the Desmidaceae.

ILLUSTRATIONS TO PROF. J.W. BAILEY'S



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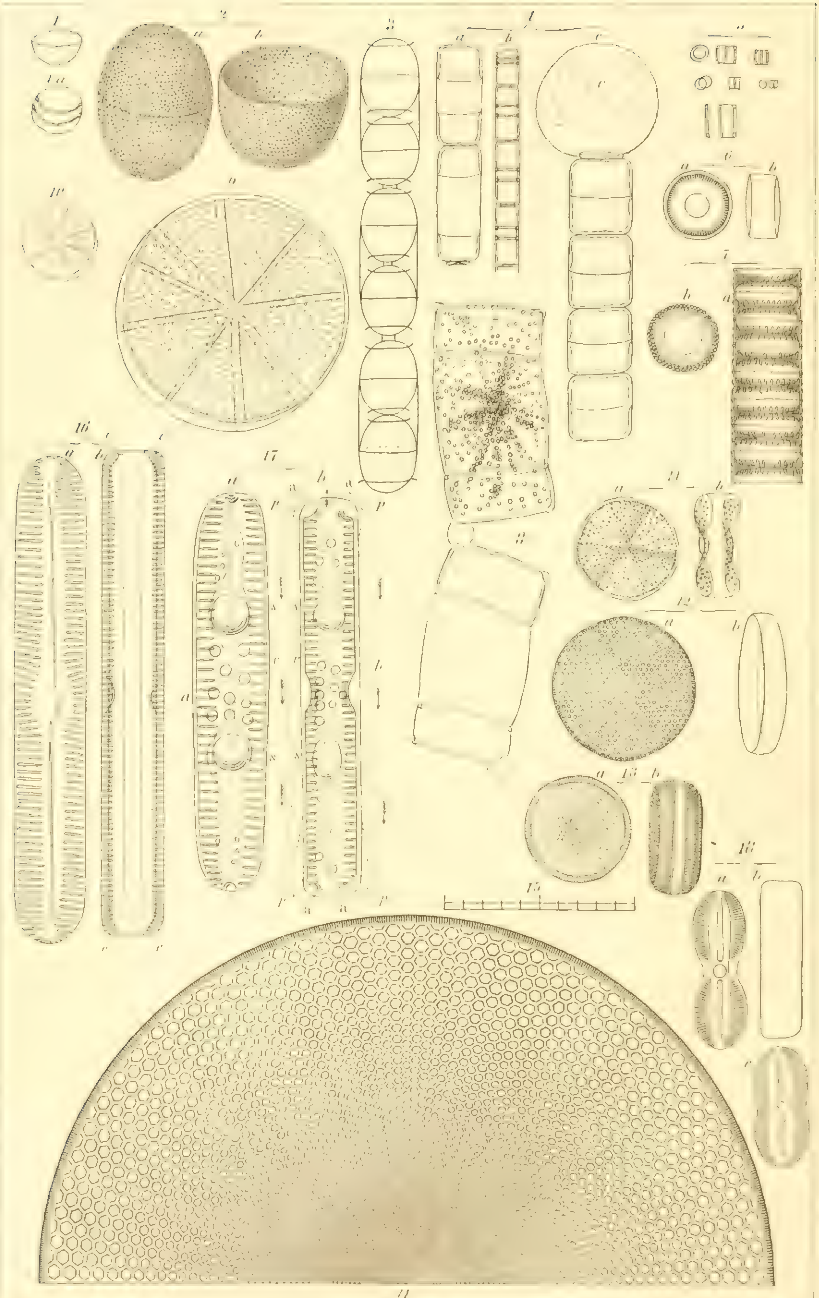
PAPER ON AMERICAN BACILLARIA



Prof. J. W. Bailey Del.

Daggett, Hinman & Co. Sc.

Plate Second, Part Second; the Naviculaceæ.

ILLUSTRATIONS TO PROF. J. W. BAILEY'S

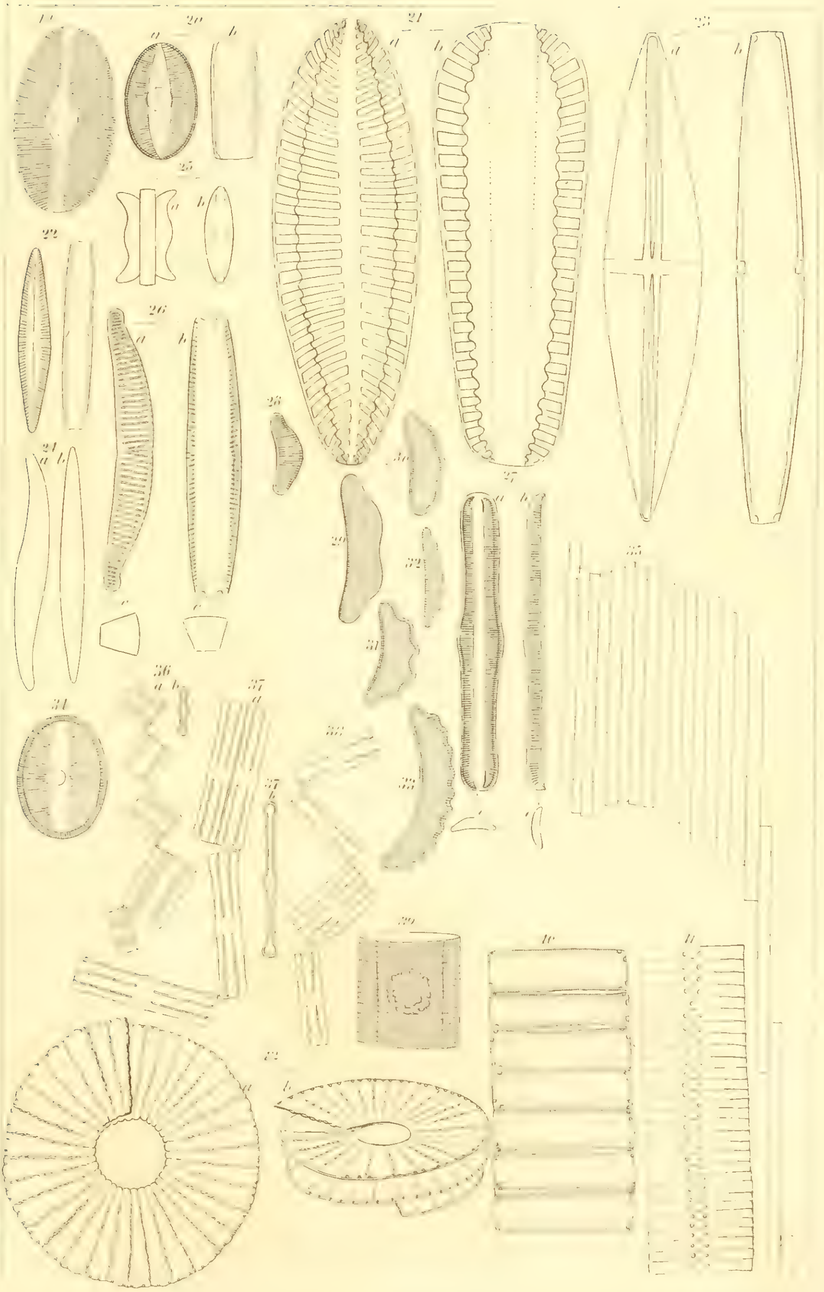


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Plate Second. Part Second. the Naviculaceae.

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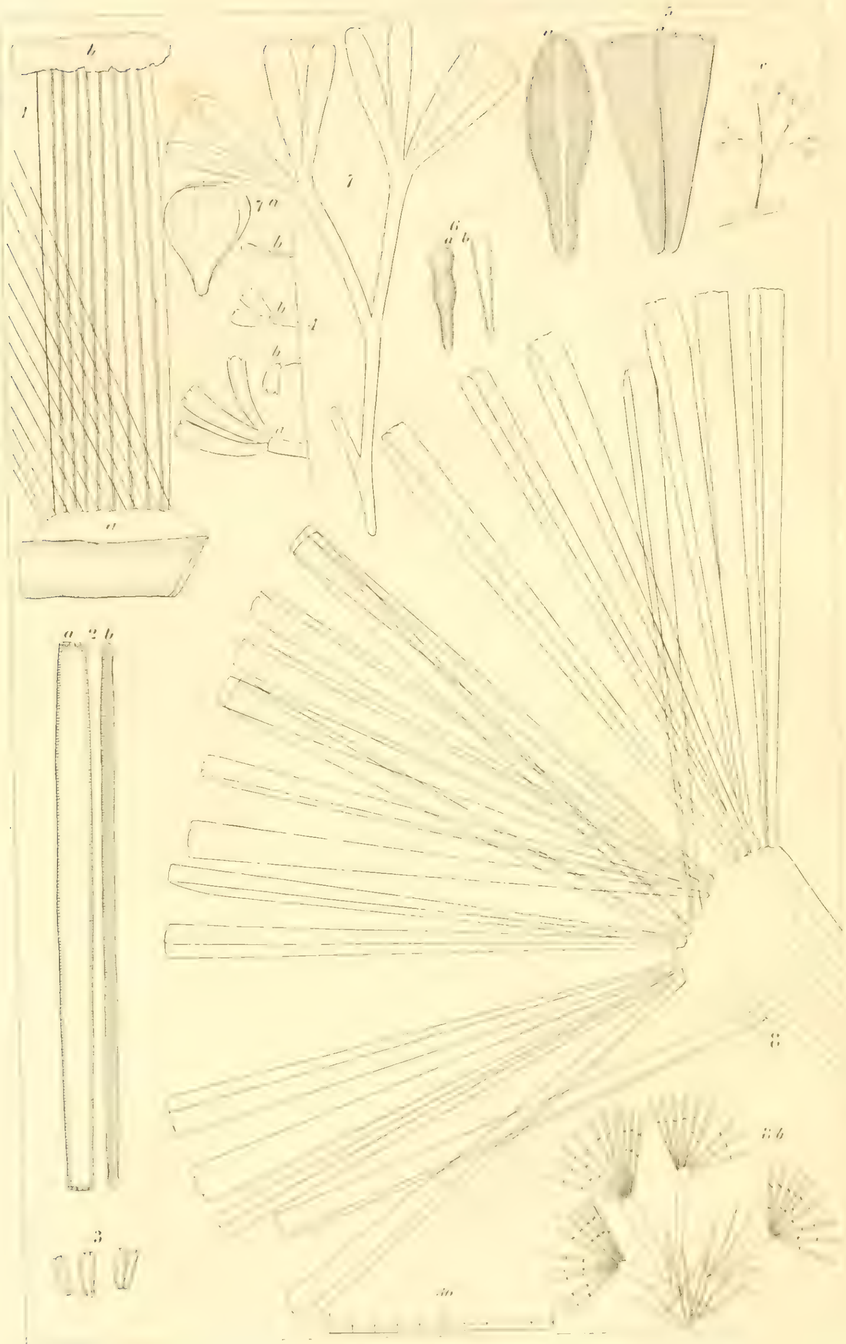

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Plate Third, Part Third.

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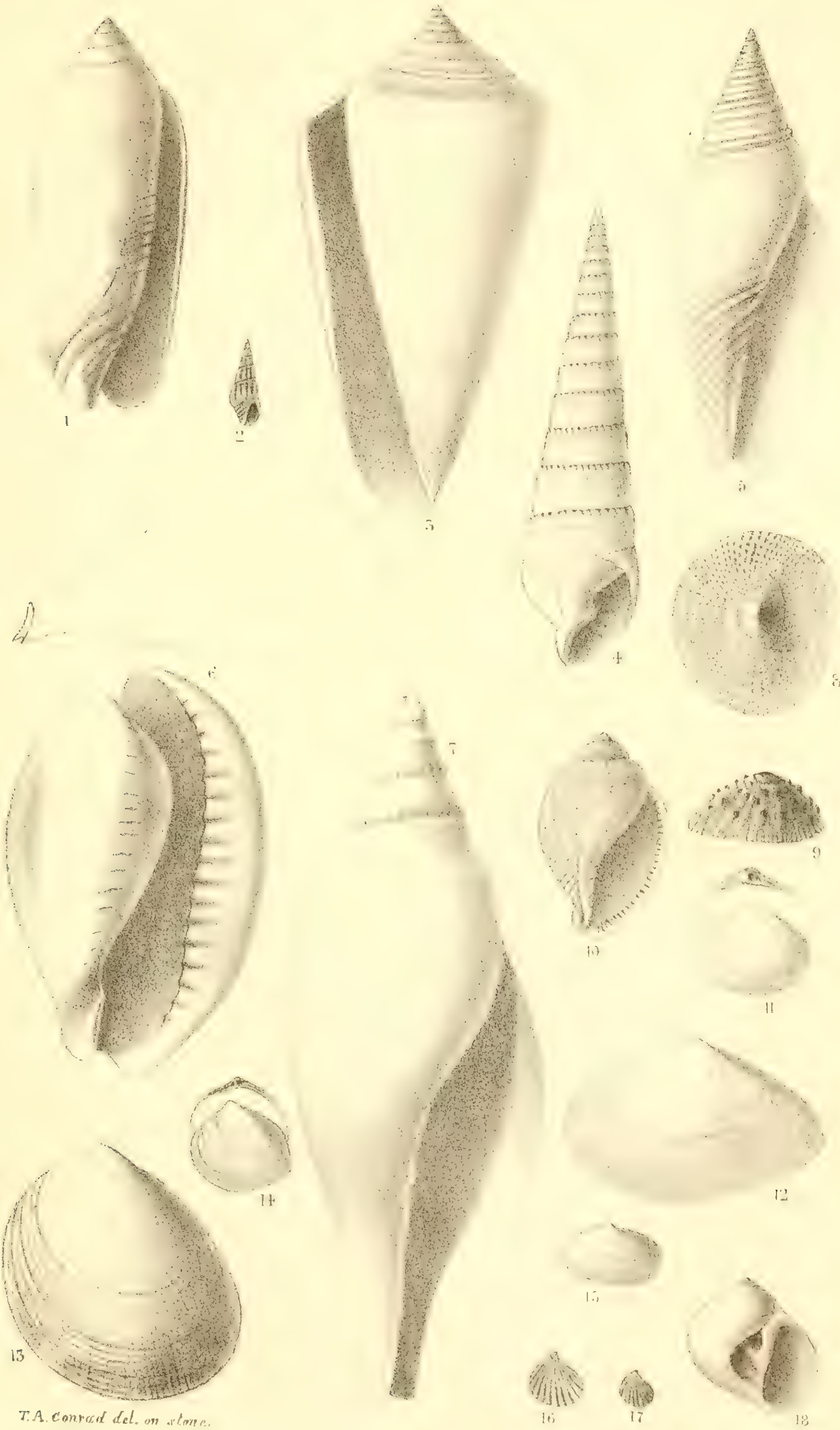
Plate Third, Part Third

PAPER ON AMERICAN BACILLARIA.

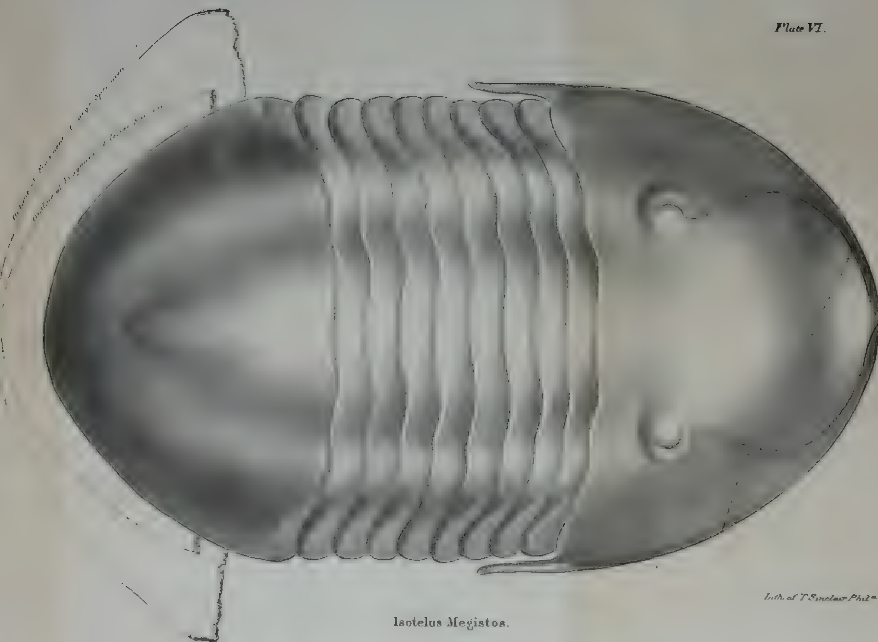
PLV



T.A. Conrad del. on stone.

Lith. of T. Sinclair, Phil^a.

Plate VI.

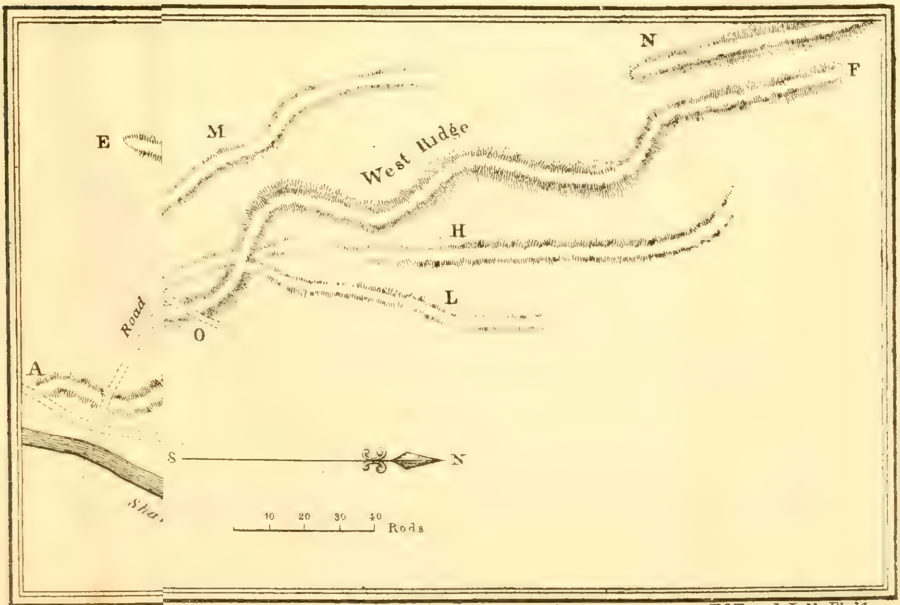


Lith. of T. Sinclair Phil.ª

Isotelus Megistos.

Plate VII.

Plate IX.



On Stone by G. Schuma

P. S. Duval, Lith. Phil[a]

Plate VII

Plate IX

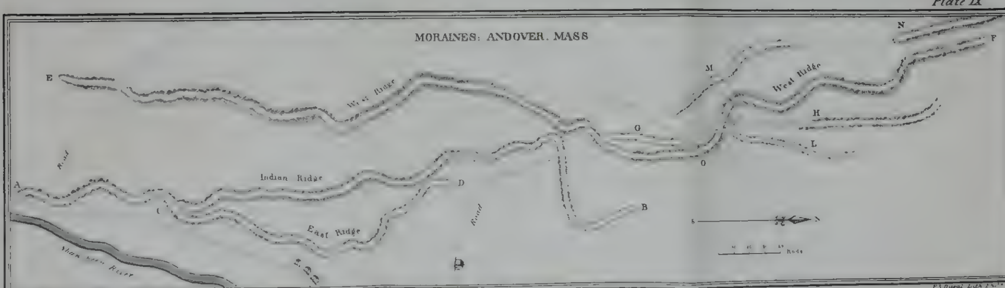
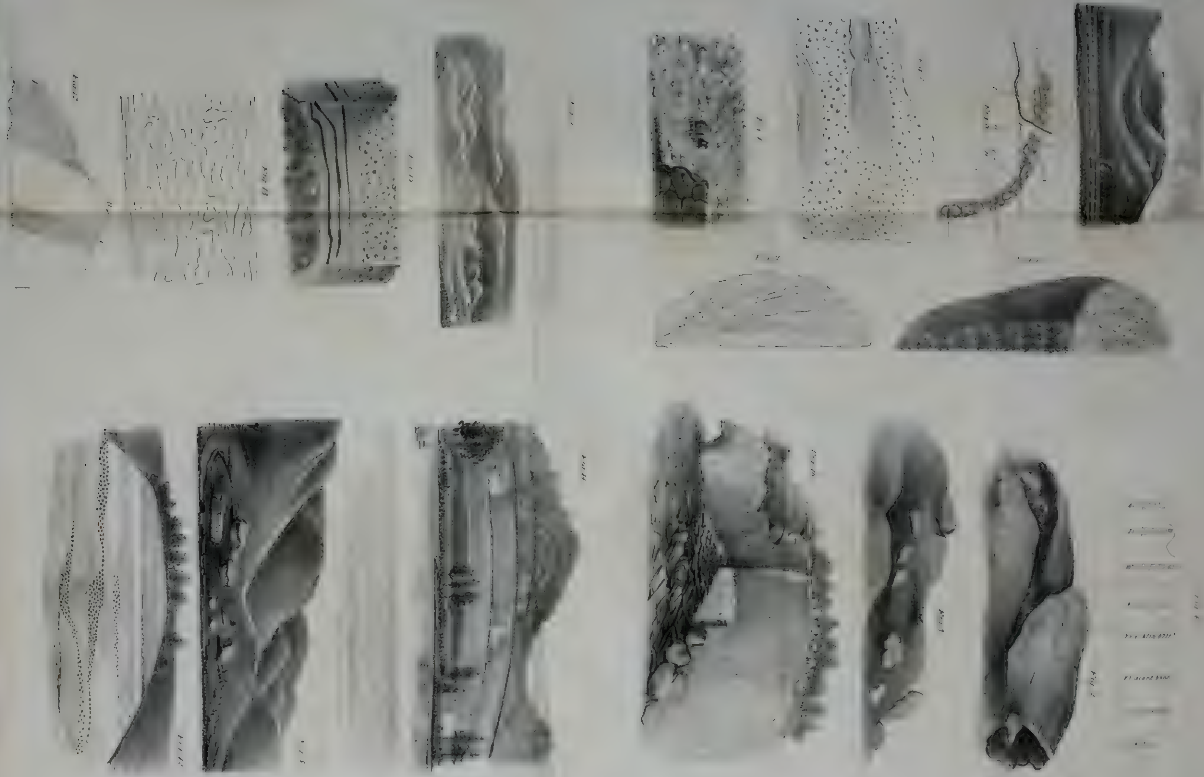
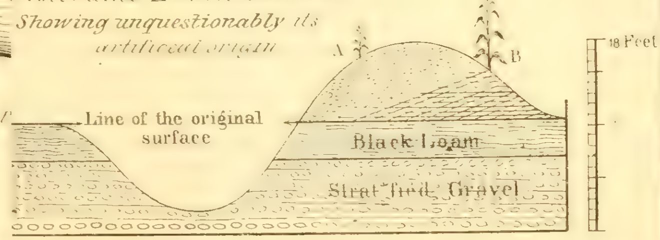


Plate VIII.



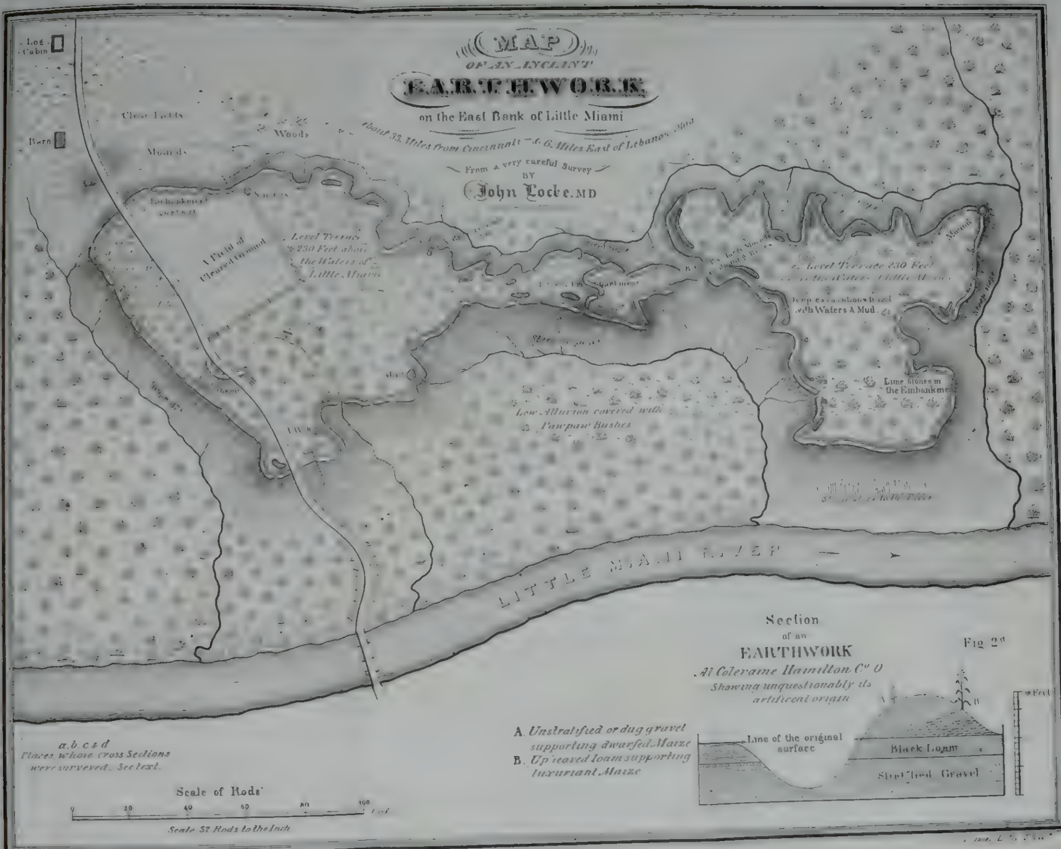
Section
of an
EARTHWORK
1 Coleraine Hamilton Co. O.
Showing unquestionably its
artificial origin

Fig. 2d



On St.

P. S. Duval, Lith. Phila.



On Stone by G. Schumacher

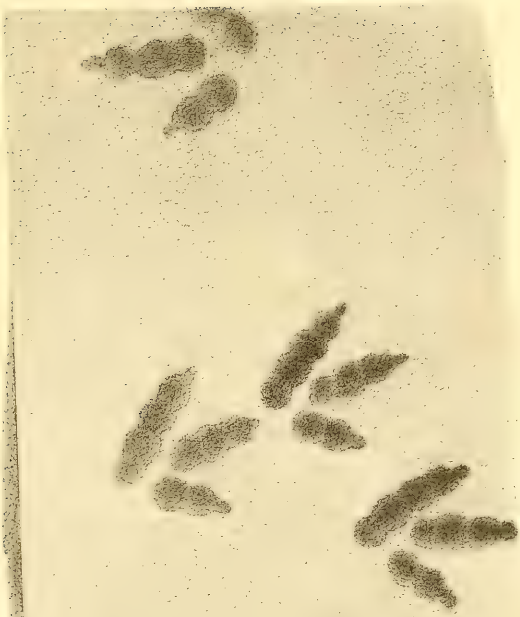
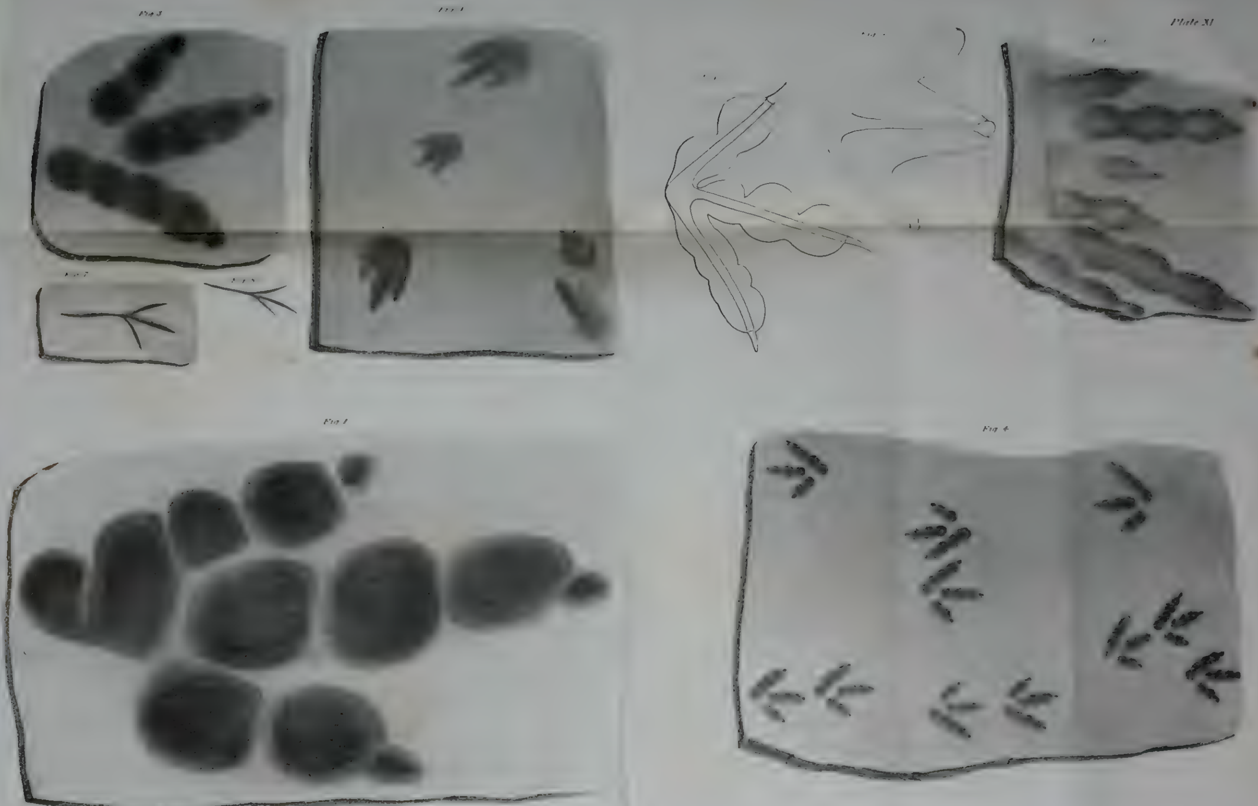
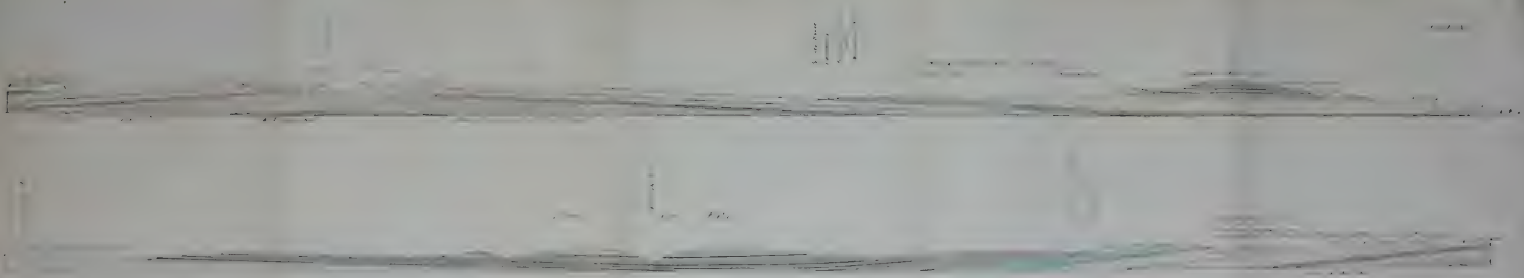
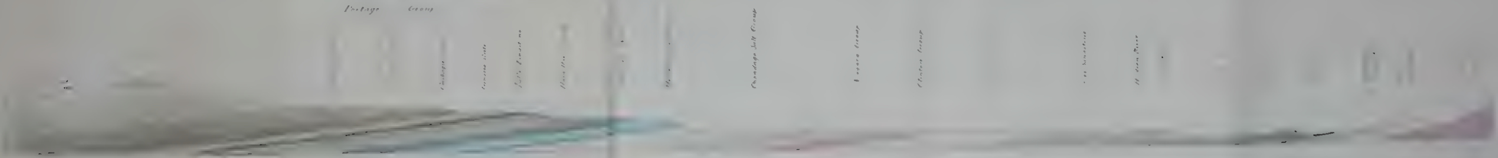


Plate XI





Section in a North East & South West direction across the Formations from Cleveland to the Mississippi River



Section in a North East and South West direction from the Primary of S^t Lawrence County to Chautauque Lake shewing the order of succession in the rocks of the New York System

Plate XIV.

Tæniopteris Magnifolia ½ Size.

Lycopodites uncifolius.

Zamites obtusifolius.

Plate XIII.

Fig. 2

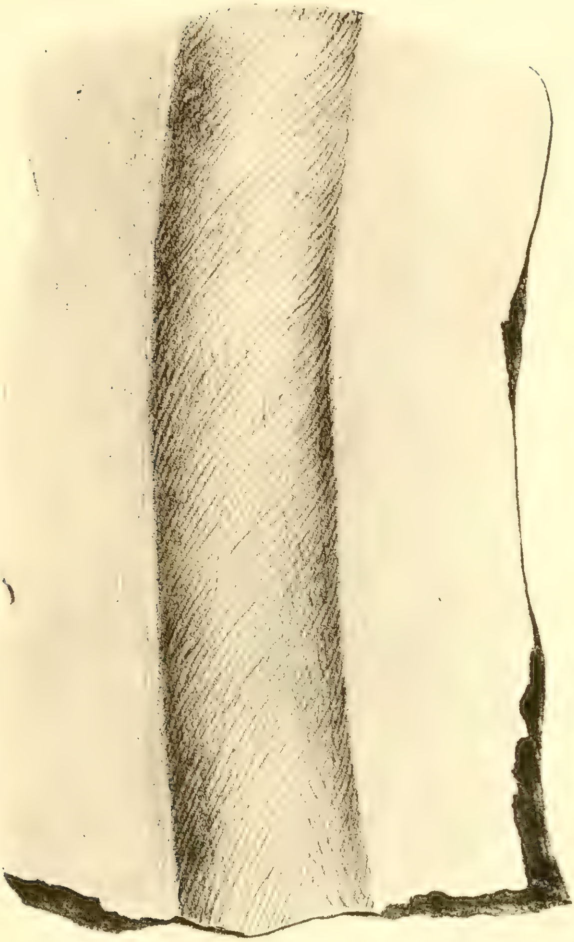


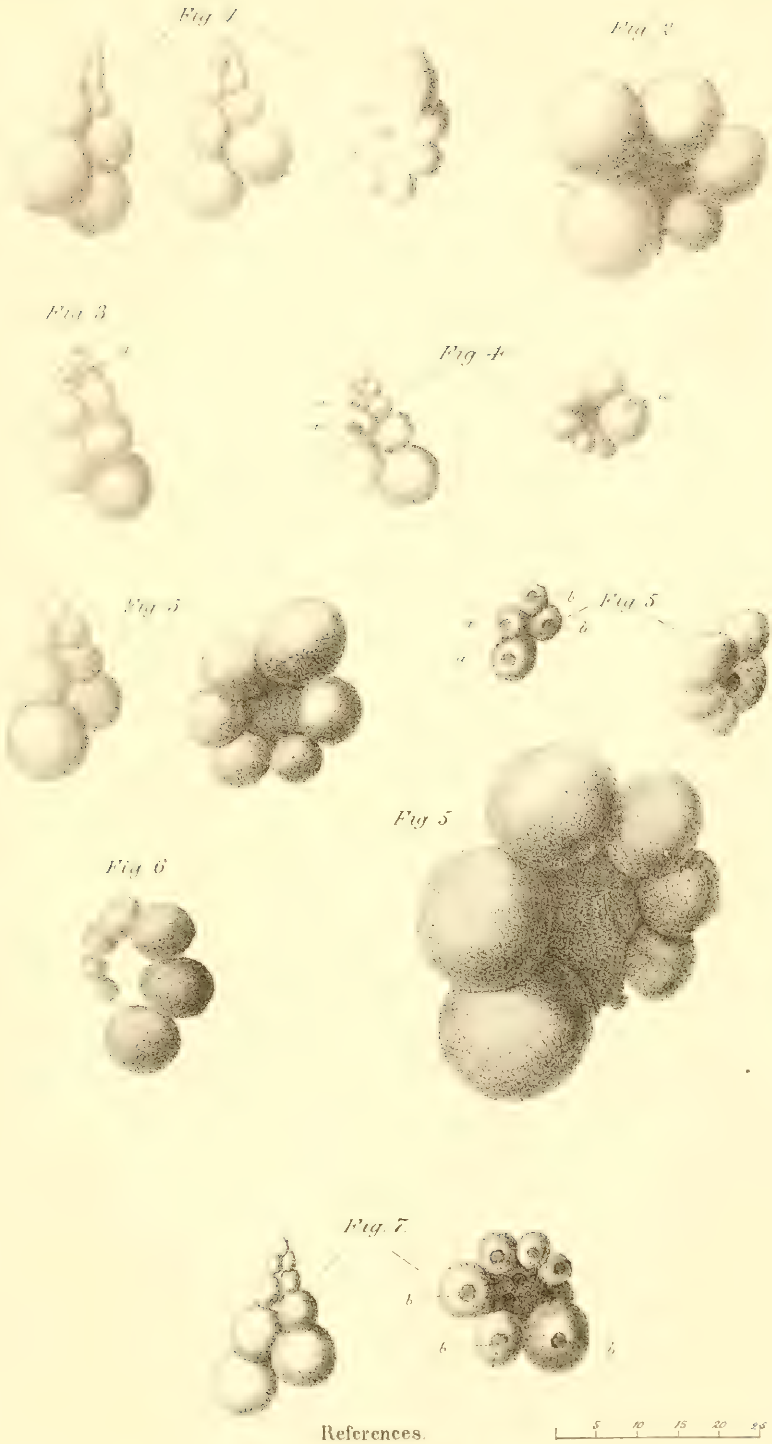
Fig 1.

Fig 3

Fig. 4.

Fig 5

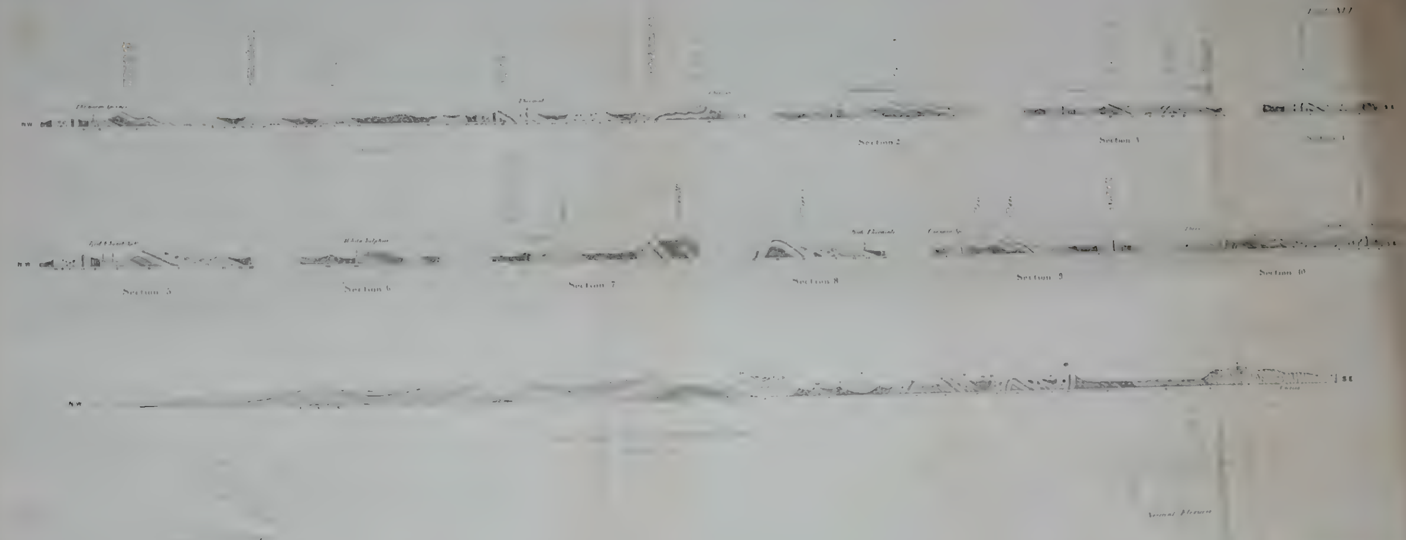
Plate XV.



References.

Fig. 1	*Damascus*	*Fig. 5.*	*Mt of Olives*
" *2 & 3.*	*Eng: Chalk.*	" *6.*	*W. Side of Anti-Libanus.*
" *4.*	*Missionary Station.*	" *7.*	*Beyrout*

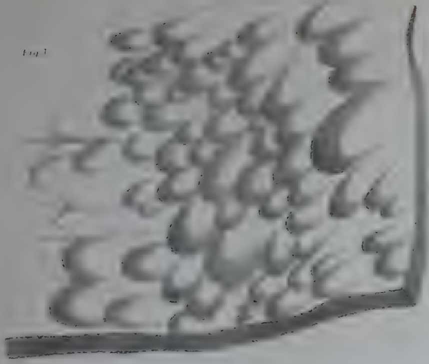
P S Duval Lith Phila



Section 2
Section 5
Section 6
Section 7
Section 8
Section 9
Section 10

Thayer & Co. Lith Boston.

Fig 1



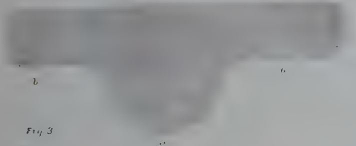


Fig 3

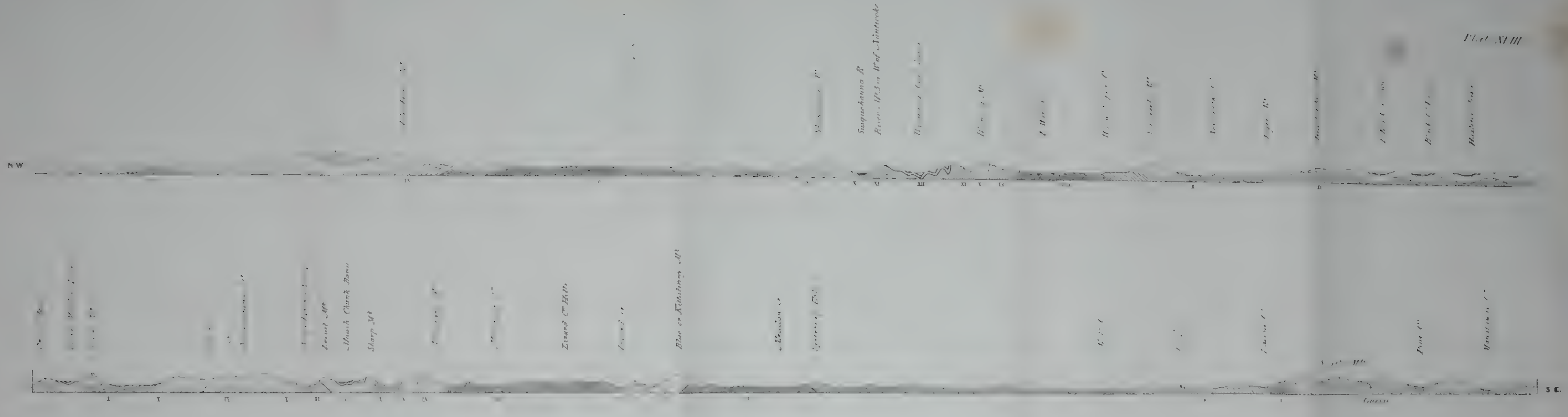
Fig 2

Pl. XVII

Fig 1

Thayer & Co. Lith Boston.

Plate XVIII



Section A.

From the Mt. Luzerne Co Penn^a to the South Mt in Berks County.

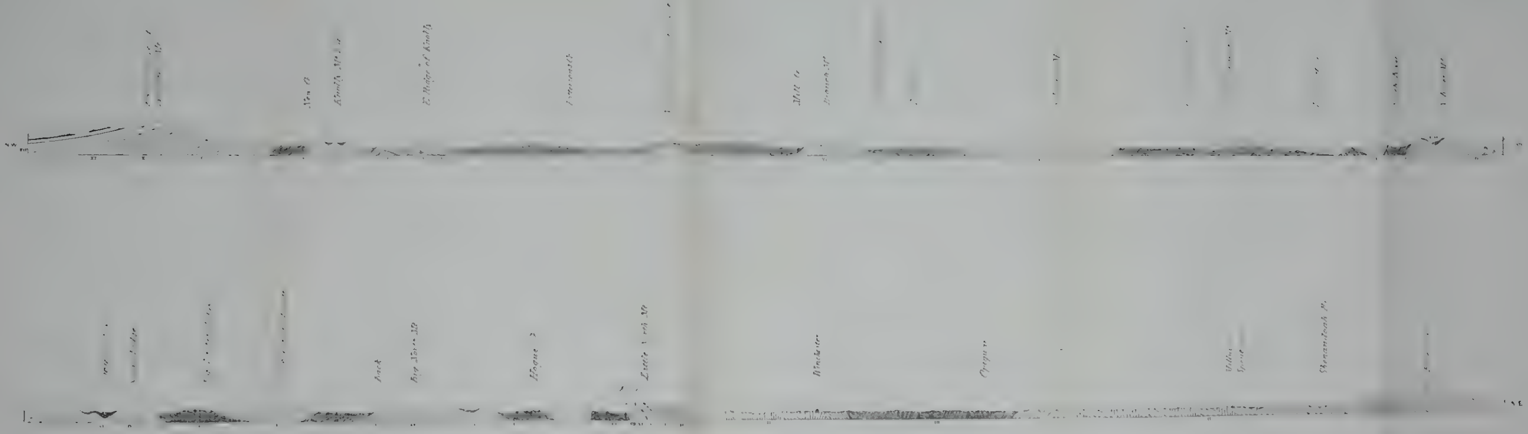
Plate XIX

Section B.

From Chesnut Ridge in Indiana County Penn^a through Armagh and Shippensburg to the South M^t in Cumberland County.

P.S. Duval's Lith Phil^a

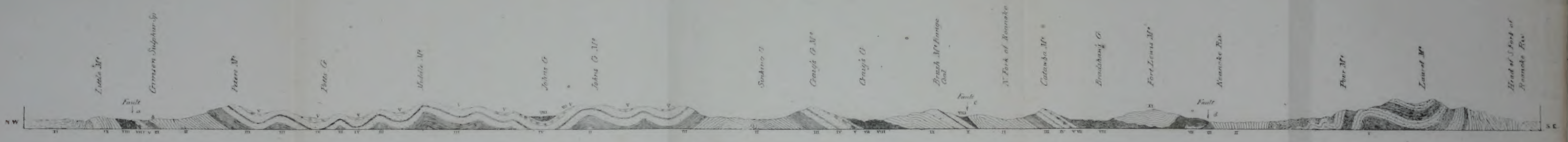
Plate XX



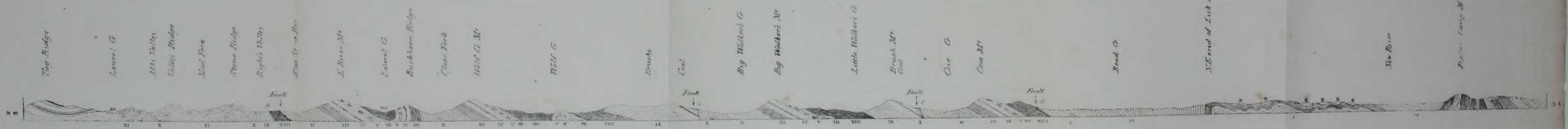
Section C

From Blue Ridge at Ashby's Gap to Allegheny M^t at N. W. Turnpike

Plate XXI



Section D. *From the Head of the South Fork of Roanoke Riv to Little Mt 5 M. from Union.*



Section E. *From Poplar Camp Mt at Poplar Camp to Tug Ridge West of Abbs Valley.*