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, Pennsylvania, 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.*