GEOLOGICAL SURVEY OF KENTUCKY.

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NOTES ON THE INVESTIGATIONS

OF THE

KENTUCKY GEOLOGICAL SURVEY

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INTRODUCTION.

In the following notes the general scientific work of the Survey and its most important conclusions will be briefly discussed. It is the intention of the collaborators of the Survey to bring most of these matters under more extended discussion, in the form of special memoirs or reports. They are given here with a view to setting forth the nature and progress of the work under consideration. The problems connected with the geology of the State will be first discussed, and then the questions of a more general nature.

Owing to the fact that the whole of the system of rocks found in Kentucky lies above the level of the Potsdam sandstone, and is practically limited to the Paleozoic series, the problems in stratigraphical geology are quite limited in their range, though of very great interest. The questions of a dynamical character are more numerous and connect themselves more extensively with the general geological history of the continent. The Appalachian system of dislocations is represented within the State by an extensive series of disturbances. The erosion phenomena of the country are extensive and varied, and should receive close study. The question of the origin of the sediments which compose the rocks of the State present other problems, the solution of which will aid in the understanding of many of the questions concerning the past history of this continent.

It is, however, in the history of the course of organic life that we find the most noteworthy matters—those which give the most important and attractive series of facts. In that history we have recorded the course of events from the time when this region lay at the bottom of an exceedingly deep sea, through successive changes, leading to greater and greater shallowing, until an infirm land was established at the time of the coal—these great swamp forests, alternating with the successive invasions of the sea; after that a vast and unrecorded time, when the principal events happened on the land, and therefore want the records of that great historian, the sea. The changes of life which accompanied these changes of physical conditions must always afford great problems for the student.

In the following pages many of these problems will be little more than stated, few or none advanced to the point where they can be regarded as having had their last word. Not the least reason for their statement is the hope that it may arouse our students to a sense of their importance:

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CHAPTER I.

The Kentucky series of rocks, as has already been stated, extend from about the top of the Calciferous series, which are the lowest rocks exposed above the drainage of the country, up to and including the lower half of the Carboniferous series. In the western part of the State there is a great covered district, where we have exposed some beds of a Tertiary deposit, belonging, doubtless, to a very late stage in the earth's history, and which is provisionally classed by the Survey as early Pliocene. Between this carboniferous section and the clearly exposed beds along the Mississippi river, we have a considerable interval where the beds are mostly concealed beneath the drainage. In this area, probably at no great depth, we most likely have several other deposits of earlier Tertiary and Cretaceous age; below these the Carboniferous system and the refined beds extend, doubtless, across the whole of the swamp region, and probably within a few thousand feet, possibly within a few hundred feet, of the surface.

The continuity of the Kentucky series was unbroken from the time of its commencement to the close of the Carboniferous, and probably later, by any change so momentous as to bring the condition of extensive dry land within its borders. After that time of emergence there is no evidence that the sea ever came to occupy a large part of the State. A general consideration of the geology of North America shows us that the Kentucky rocks are only a small and not distinctly limited fragment of a series of formations which may be termed the Mississippi series, though they were mostly formed before that valley had a distinct existence. It will, therefore, often be necessary to pass beyond the limits of the State in order to obtain clews to that which may be hidden within its limits.

Looking into other parts of the Mississippi Valley, we find that there have been extensive deposits, formed at various points, which are of a date much later than that of the carboniferous limestones, and yet older than the clay beds of the Hickman series. These beds of the Permian, Triassic, Cretaceous, and early Tertiary age, come in as we go either to the westward, where they all are found covering considerable areas, or to the southward, where only the last two series appear at the surface. The presence of these deposits within the division of the continent to which Kentucky belongs, may fairly entitle us to ask whether they had been deposited here, and afterwards worn away, or whether they were never laid down over this region. This point has never been carefully considered; and as its determination is a matter of considerable importance, we will have to discuss it in some detail.

The first point requiring attention is the fact that this region is being worn down at a relatively rapid rate. The data for fixing the precise average down-working of the surface have not yet been determined, but a study of the facts obtained by the researches of Humphreys and Abbot for the Mississippi river will enable us to approximate to a satisfactory conclusion. The conclusions based thereon are to the effect that the Mississippi discharges from its mouth, in the shape of dissolved mud and coarser sediment, pushed along by the current on the bottom, matter enough to form a stratum one foot thick over the whole surface of its valley in about seven thousand years. To this total the several sections of the valley contribute very unequally. The rain-fall of the several regions varies greatly, and the region occupied by Kentucky has at present far more than the average rain-fall. The data for a very accurate determination of these points do not yet exist; but enough is known to enable us to say that, area for area, the Ohio Valley yields about twice as much sediment as the Missouri Valley; so that one foot in depth in about three thousand five hundred years has probably been about the rate of the erosion of surface during the time immediately antecedent to the present day.

Nothing in the physical conditions of the earth is so variable as the rain-fall in particular districts; every uplift and downthrow of land on the earth's surface, if it be considerable, must propagate its efforts throughout a hemisphere; but we may with safety assume, that, ever since the Rocky Mountains were formed, the relative rain-fall of the two regions represented by the drainage basins of the Ohio and Missouri has been about the same. Whatever would tend to increase the rain-fall of the Missouri district would probably tend to bring up that of the Ohio. There is nothing in the way of changes in the past, so far as we can see, which could have tended to lower the rate of rain-fall, and consequently to diminish the rate of erosion in the Ohio Valley; on the contrary, as I shall endeavor to show in the fourth chapter, the last recognizable change brought diminished rain-fall, and that for a period of many thousand years, this region was the seat of a precipitation far more active than at present. No definite weight can well be given to this fact; but it doubtless serves to show that the estimate of erosion given above is probably not excessive. Assuming, then, that each million years will take away about three hundred feet from the surface of the country, the question arises, how much time has elapsed since the Carboniferous period was completed—the last of the general formations of the State. The science of geology has never attained to that accuracy which will enable us to give definite answers to such questions; but certain general estimates have been made which probably have a certain value. Without digressing into a discussion of these methods, we may say that those geologists, who have attentively studied the natural records of the earth's surface, would all agree that the Carboniferous period must have closed at a time certainly more than ten million, and possibly more than twenty million, years ago. Without attaching too much value to these estimates, we see that something over three thousand feet of beds must have been worn away from the surface of this region since they were uplifted above the sea level. The only way in which this conclusion can be greatly limited is by the time to be allowed for the deposition of the beds which have been lost by erosion. This may much reduce the amount of the erosion; but it must still leave it probable that a great thickness has first been deposited, and then eroded from this region, since the Carboniferous time.

Many reasons concur to make us believe that this additional thickness of beds was on the whole principally of Carboniferous and Permian ages. These reasons are substantially as follows: The greatest single movement of the Appalachians in their uprising was at the close of the Carboniferous time. Now, there are many reasons for believing that this extensive flexing of that chain was accompanied by a general uplifting of the whole continent, or at least that broad western sloping table-land which lies against the Appalachian Mountain system, and is in effect the table-land element of that chain. Furthermore, the Mississippi Valley, at least its central section, seems to have moved tolerably together in its upheavals and subsidences since the beginning of the sub-carboniferous limestone. Moreover, in western Pennsylvania, we have a thousand feet or more of beds, which lie on top of the topmost part of the Kentucky section, and in the Missouri Valley we have an extensive series of Permian deposits, which may well have lain on top of all we have in Kentucky and Pennsylvania. These beds may well represent the section which has vanished in Kentucky, as a consequence of continued erosion. It is possible that other sets of rocks may have rested on the top of these—the uppermost beds of the Paleozoic series; but I think it quite unlikely that this part of the Mississippi Valley has been resubmerged, and the seat of marine accumulations, except on its extreme western border, and this only to a slight extent.

There are in the Southern States, about the Gulf of Mexico, vast deposits of detrital materials, which are probably the waste from the upper Paleozoic rocks and underlying formations, of the exposed parts of the continent. Owing to the peculiar position of these regions, it is difficult to see any other source for their deposits than this northward-lying section of the North American continent. These beds, in their turn, have been greatly wasted; but enough of their mass remains to represent some hundreds of feet in thickness of beds over the whole of the Mississippi Valley.

There are some peculiar features in the organic life. The gar-pikes of the Mississippi system of waters, though extending, it is true, eastward to Lake Champlain, may be regarded as essentially characteristic of this river system of the central valley of the continent. This form is fully recognized by naturalists as a relict of an earlier assemblage of life, which was generally extinguished at the close of the Paleozoic time, and has only survived in corners of the earth since that time. If the whole of the water system it inhabits had ever been submerged at the same time, it is reasonable to presume that this race of animals would have been exterminated. It is, therefore, fair to presume that there never could have been conditions suited to the formation of extensive deposits, covering the whole valley, since the carboniferous period, or thereabouts. There is another piece of evidence likewise derived from the organic life of our rivers, but in this case from a group of mollusks. The unionidæ, as is well known, have a very extensive development in the Mississippi Valley, especially in its Ohio waters. The diversity of species in this section much exceeds that which we have in any other region; indeed, it seems likely that there are more species to be found in these waters than could be found in all the other waters of the world. The only conclusion to which we can come is, that the group has been freer from the invasions of the sea in this region than in any other, and that here, as in the case of the gar-pike, the necessary conclusion is, that the forms have been from a very ancient date safe from the invasions of the sea; the great lapse of time having given an opportunity for great increase in the number and the variety of species. Something of the same nature may be concluded from the character of our American forests. Many genera, which have existed in Europe during the Tertiary era, have died out there, and only remain in existence on this continent. This is notably the case with the genera *Liriodendron*, *Liquidambar*, *Nyssa*, &c.

These genera are now peculiar to our Mississippi Valley and other neighboring forests, but they once flourished over central Europe. Invasions of water, and probably also of ice, have served to extinguish these forms there, while in America they have withstood the dangers of time, and remain little changed over a great period. This immutability can best be explained by supposing that this region has remained in great part unsubmerged.

The caverned regions of the State are in themselves enough to assure us that there has been no great submersion of the region during the last million or two of years. Any such submersion would be necessarily attended by very great changes in these wonderful structures. They would probably become closed to a great extent by marine deposits, while the superficial marks, which would be made by a short occupation of a country by the sea, might be effaced by the erosion of a million of years, or even less. The cavern record ought to last a good deal longer.

While denying that the general surface of Kentucky has been beneath the sea since the Carboniferous period, we are driven to acknowledge that the western section along the Mississippi has been so far depressed that it has been able to accumulate beds, having a thickness of at least three hundred feet above the level of the river. From an imperfect examination of these beds, I am inclined to think that they were rather fluviatile than marine in their character. Yet, I am disposed to think that they were nearly on the level of the sea at the time of their deposition. It must also be noticed that inasmuch as these beds wear with considerable rapidity, the million of years which must have elapsed since their formation may have been attended by a loss of over one hundred feet in height. A sea carried over the country to the height of one hundred feet above the bluff at Columbus or Hickman, would extend over the State for a considerable distance to the eastward. By our conditions, it would meet a higher country in that direction, owing to the loss which has taken place over its general surface during the time which has elapsed since the close of this subsidence. It seems likely that the eastward line of such a sea, assuming it to have been created by a general and not a local subsidence, would have fallen east of the Tennessee river; and that along the Ohio and other rivers it should have penetrated some hundred of miles further. The entire and well established absence in these basins of any such deposits is a striking and nearly complete evidence of their local nature.

It is not to be believed that, in the many sheltered nooks, where they could have been preserved by favoring conditions, they have all been lost, while in the very line of the Mississippi, exposed to repeated assaults of one of the most destructive of streams, they have alone survived. It is easier to suppose some local and peculiar forms of elevation, acting at this point, than to suppose the total destruction of all the other fragments of a great even sheet, except these detached and exposed masses. There must have been a considerable area of this elevated country, but it could hardly have had the extension which we would naturally have expected from its considerable altitude and its general character. It may be that there is some connection between the formation of a rather local series of elevations in this district and the occurrence of strong disturbances, such as that known as the New Madrid earthquakes, in 1811–'13. At that time we had in the region of Reelfoot Lake, as we shall see in the subsequent chapter, a down-sinking of a great district to the amount of ten feet or more. An uprising similar in its origin may account for these remarkable insular masses of elevated land.

It may be well observed, that if these masses had been part of an equal level plateau, the deposit should have filled up a large number of the Green river caves, and would have barred the northward course of the Tennessee and the Cumberland rivers by filling their valleys. As it is, the supposition that these Hickman and Columbus ridges are part of an ancient local elevation, would enable us to account for the fact that the Cumberland and Tennessee rivers flow so far to the north and join the Ohio rather than the Mississippi, towards which the general direction of the drainage should direct them. Such a barrier may have turned river courses to the northward and maintained them there until their new beds had been formed.

The next question as to the prehistoric changes of Kentucky is concerning the original horizontal extension of the several formations found within the State. An inspection of the accompanying geological map will make it plain that there are at present two distinct areas or geological basins, as they may be called, which lie within the State: one of these is the eastern coal field, and the rocks which lie below it, and the other the western coal field and its little-known underlying rocks. The barrier which separates these fields is the long low ridge sometimes known as the Cincinnati axis, but which ranges from the State of Alabama on the south to central or northern Ohio on the north. This axis has some important features which throw no little light on the general dynamics of the North American continent. In a subsequent chapter its character will be extensively discussed; it is only necessary for us, in the present connection, to determine when it was formed and to what extent it separates the region on the west from the east. The diagrammatic sections in this report will serve to show its general relations to the rocks on either side. It will be noticed in the maps, that the several formations of the State show escarpment faces turned towards this central ridge, and the student in the field will readily perceive that these erosion faces are steadily retreating from the central part of this ridge. He will also perceive that the ridge itself has certain peculiarities which separate it from all ordinary mountain ridges. It is singularly wide, being at least fifty miles across, and very low, not rising more than three to four hundred feet above the general plain of the Ohio valley.

A careful study of this ridge has convinced me that it was begun at a very early day. The beds exposed at the level of the Ohio opposite Cincinnati show a good many pebbles of limestone rock imbedded in the limestone and shale. At the same point, and in the overlying rocks, for one hundred feet or more of height, the beds show occasional layers of broken shells packed together as by strong currents. This is especially noticeable in the beds containing *Strophomena alternata* which occur throughout this section. These facts point to the conclusion that these beds were formed in shallow water, and that this shallow water was swept by strong currents. Beneath the Cincinnati Group there is an extensive system of sandstones or other quartzose rock. This is shown by the matter brought up by boring made near Cincinnati, which I examined in 1868, when, from the depth of two hundred and seventy feet below the bed of the Ohio river, the auger brought up a fine silicious rock, seemingly the fragments of an open-grained sandstone. From this rock, and from the beds just over it, issue a great number of saline springs, which occur all along the Cincinnati axis. There is no other way of explaining these springs save by supposing that they are flowing from deposits of salt laid down when this region was near the surface of the water, so that great salt marshes were formed, to which the sea water had but difficult access, so that, by evaporation, quantities of salt were laid down. These several facts—the occurrence of salt deposits at one level, pebbles at a point some hundred feet or more higher, of broken shells at yet another hundred feet up in the section, and finally of salt deposits again in the blue-grass limestone, which forms the summit of the Cincinnati Group—gives us fair reasons to conclude that this series of deposits was formed in a region which was balanced near the top of the ancient seas. On the other hand, on the east, in the region now occupied by the head-waters of the Tennessee, the beds deposited at this time were all made in deep water, without any of the phenomena which indicate occasional elevation of the bottom to the surface. I have not personally examined the equivalent beds in Illinois, but I believe from the descriptions that they likewise fail to show these alternations of condition which indicate shoal water. Even the equivalent beds in New York, although formed near a shore line, fail to show anything like as much evidence of the successive uplift into land conditions of that region as is shown about the Cincinnati axis.

Along with the evidence already cited to show the ancient character of the Cincinnati uplift, we may cite the extraordinary frequency of sandstone beds at some points in the series, particularly at about one hundred feet below the top of the section. This shows that the shore line probably came near to this region a number of times when the bottom did not actually arrive at the surface.

The Cincinnati series in this section is closed by a sandstone, ranging from five to fifty feet in thickness, entirely barren of organic remains. The history of this rock is not easy of determination, but it is peculiar to the Cincinnati axis, and marks one of those sharp transitions which are so prominent a feature in this section, indicating the rapid successions of upheaval and subsidence which resulted in giving us a broad irregular mountain fold traversing the State.

The existence of recurring upheavals since a very early time makes it doubtful when this axis of elevation came above the sea so as finally to interrupt the deposition of strata. It was at first assumed by geologists that the beds of the carboniferous and all the underlying strata down to the base were laid down continuously over the whole of the Cincinnati arch. More recently it has been announced, with almost equal want of definite proof, that the elevation has existed from a very ancient time, and that the eastern and western coal basins were deposited in areas which were separated by high and dry land, in this region. In both these conclusions no reference has been made to the erosion rate of the surface, nor any attempt to reconcile the conditions of this action with the theories on which they rest.

The sections given in this volume show us that the Cincinnati Group is continuous over the arch at points where the cutting is deepest. They further show that the upper Silurian continues over a large part of the area in a more or less fragmentary way: its waste is found on the tops of some of the highest hills as detached outliers. Above this comes a very soft formation, the Devonian black shale or Ohio shale, as it will be called in these reports. The absence of the outliers of the Carboniferous and Waverly series is, I am inclined to think, dependent on the softness of this bed, and the rapid destruction which would overtake outliers which rested upon it. This accounts for the tolerably continuous front of the Carboniferous series in northeastern Kentucky, where this bed is thick, and the increase of outliers in the southern section of the western front of the eastern coal field, where it is thinner. The more rapid retreat of the beds away from the Cincinnati end of the axis than from the region penetrated by the Cumberland river is, in part at least, doubtlessly due to the greater thickness of this formation in the region along the Ohio river, and the consequent more rapid wearing back of the escarpment. If we allow that one hundred and forty feet of beds wear off of this region each million of years, then, at that distance in the past, we had the whole of the Niagara Group stretching across the arch at Lexington, and covering almost the whole of the arch throughout its extent from Cincinnati to Nashville. The only sections which would have been cut deeper would have been the stream beds themselves. Another million of years into the past would give us the Ohio or black shale over the greater part of this area. We would probably have to go something like two millions of years further back to find the time when the greater part of the Waverly series still rested on the whole of the summit of the Cincinnati axis. This is only taking the average rate of wear for the Mississippi Valley. We have seen that it is more probable that the rate for the Ohio Valley is nearer three hundred feet in a million years. On this basis it would only be necessary to restore the wear which has taken place during the last two million of years to return to the Cincinnati axis all the beds up to the sub-carboniferous limestone, over the region where now the surface is cut down to the Cincinnati Group. The same method of determining the changes of the past would lead us to conclude that, between four and eight million years ago, the surface of the country over the Cincinnati axis lay within the coal-bearing rocks. There are only two conditions which could essentially invalidate this reasoning. There may have been other beds laid over this region which have taken the brunt of the wear, or the rate of erosion has been on the average less rapid than our hypothesis supposes. The first of these objections seems to me to have little weight, inasmuch as the wide expanse of country that must have shared this deposit has failed, on narrow search, to reveal the slightest trace of any such beds in any of the valleys or other places where it might have been sheltered from the erosive actions which destroy the geological records.

This absence of even fragmentary remains is always a very decisive circumstance, tending to show the non-deposition of any particular beds in any given district. Such non-conformable beds are apt to last longer than any single element of a series, on account of the greater variety of conditions under which they have been deposited. The other possibility in the way of the general conclusion as to the beds which have been eroded is, that the rate of wear may not have been, on the average, as great as that which has been supposed in our computations. To this it may be said, that not only is the time a low estimate, but it may also be fairly concluded that, during a large part of the past, the rate of wear was materially greater than at present.

Before leaving our consideration of the Cincinnati axis I desire to say a word concerning the age of its formation. We have already seen that during the later Cambrian time it was in a state of constant oscillation. If the evidence is read aright in the foregoing pages, these oscillations seem to have left it, at the time of the last deposits of the Cincinnati Group, still well depressed beneath the water; for the Cumberland sandstone, which lies on top of that series, is never mixed with pebbles, and could not have been deposited except at sufficient depth to have secured a tolerable uniformity of conditions. If this axis had furnished shore lines during any part of the time occupied by the formation of the succeeding beds of the Silurian, Devonian, and Carboniferous periods, we should expect to find some indications of the fact in the existence of pebbles derived from these shores. The Devonian black shale, it would seem, ought to show a certain amount of calcareous material in those portions of its area which come near to the axis. The absence of such deposits may possibly be accounted for by the stillness of the waters in which these beds of the Ohio shale were laid down; but in the Waverly series of rocks we have a great thickness of deposits composed of sand, which show currents strong enough to transport materials from a great distance, but no trace of matter which could have come from the Cincinnati axis. Moreover, if it had supplied large quantities of detritus it would cause all the beds deposited against it to thicken as they approach it. No such indication can be discerned. The Carboniferous Conglomerate, on the contrary, increases in thickness as we recede from the Cincinnati axis. It contains great quantities of pebbles, both in the east and in the west, but not a trace has yet been found of any pebbles which could be attributed to the Cincinnati axis. The mountain or sub-carboniferous limestone passes across the axis in the low section between Nashville and Cincinnati, making what is known on its escarpment as Muldraugh's Hill. This part of the field must have been quite near the ancient shores, if there were any, as it is not over fifty miles from the highest point on the Cincinnati axis. Yet this deposit shows here the same evidence of remoteness from shore lines, whence detrital matters could come—the same evenness of texture and absence of those alternations of materials which always mark shallow water beds.

Along the Cumberland River section the inferior measures of the coal series in the east and west approach so closely to each other that it is said to be possible, in very clear weather, to see across from one section to the other; the high outliers of the Carboniferous system supplying the intermediate links, so that the actual break between the coal fields is probably not more than forty miles. The replacement of one hundred and fifty feet of beds which have been worn away would probably unite the coal fields of the east and west by making the lowest beds of coal, which, as we shall see in another chapter, come in the upper Chester series, continuous across the whole central region of the State. It is impossible to resist the conviction that a million of years or thereabouts ago this section still contained a continuous sheet of coal reaching from Wayne and Clinton counties on the east, across to Edmonson and Hart on the west.

I believe that the uppermost level of caves which remain open in this region were formed during the time when the hills of this section were still so continuously capped with the remains of the coal fields that there could have been no doubt as to the continuity of the two fields—the eastern or Appalachian, and the western or Illinois field. This original continuity being granted, the most material question as to the relations of the two coal fields is substantially disposed of. Going north or south of this line, more and more time for the erosion becomes necessary, for that erosion increases progressively, until at Nashville or Cincinnati we require a duration which is probably somewhere between four and eight million of years for the completion of the down cutting from the true coal measures. Although the discussion of the dynamic geology of the Cincinnati axis must come in the fourth chapter of this report, there are some reasons why we must prolong the consideration of it here until we have determined, as well as we may, the time of its formation. Inasmuch as there are facts going to show that there were successive upheavals along the line of that axis at a very early day, viz: in the time of the Calciferous Sandstone and the succeeding ages up to the upper part of Cambrian, I am inclined to believe that the upheaving action began in this region at the beginning of the time before mentioned. But, inasmuch as this whole region seems to have been depressed beneath the sea during the period when at least one thousand feet of successive beds were forming, it is difficult to escape the conclusion that this elevation could not have been very considerable, and must have either been quite effaced or have been borne down by a subsidence of the whole continent, so that it made no obstacle to the uniform deposition of beds.

It is difficult to form a satisfactory opinion as to the time of the last elevation of the Cincinnati axis. The most noticeable feature is, that, while the Cincinnati and Nashville sections of it are geologically three to four hundred feet higher than the section lying between Wayne and Hart counties, yet these two first named regions are cut even lower than the section lying between them. If the ridge had been elevated with anything like the suddenness that has characterized the upheaval of many mountain ridges, the several rivers that traverse it would have shown more indications of disturbance of their courses than they exhibit at present. They are, however, not altogether wanting in deflections, which show their contact with the axis—the northward inclination of the Ohio—all the way from the mouth of the Chatterawah or Big Sandy, until it makes an angle on the summit of the axis at Cincinnati. The sudden bends in the Kentucky, in passing through Madison, Fayette, Jessamine, and Garrard, may be due to the changes brought about by the elevation of this axis. That of the Kentucky river is doubtlessly, in part, due to the Dix river fault and the associated dislocations, all of which are probably due to this fold of the Cincinnati axis. The southward bending of the Cumberland, in Pulaski county, is more distinctly the effect of this axis. In its course, this stream shows something of the same peculiarities as belong to the Ohio: they both turn away from the general trend of their basins, in what appears to be an effort to avoid the central region of the axis, and, after passing it by, return at once to their normal courses. While feeling much doubt about the conclusion, I am, on the whole, inclined to think that this axis has been the product of a number of successive elevations rather than a single upheaval; and I am furthermore inclined to believe that the principal part of this uplifting came after the close of the Carboniferous time.

CHAPTER II.

In this chapter I shall consider the succession of the Kentucky series of rocks from their lowest to their highest members. A great deal remains to be done before the whole of this history can be gathered, but its general outlines are tolerably well known. While much that will be given in the sequel is already well known from the study of other western rocks, there are many points which are now discussed for the first time, and have the light of the observations of the present Kentucky Survey to aid us in our understanding of them.

Owing to the comparatively undisturbed character of the Kentucky rocks, the area of the State does not give us a single point where we can see deep into the more ancient part of the section of the stratified rocks. The appended diagrammatic section will show how small a part of the beds above the rocks, which show no distinct trace of having been laid down from water, are exhibited within our limits. It will be seen that not more than one tenth of the total section lies exposed in Kentucky, and that there are probably something like forty thousand or more feet of rocks deposited in ancient seas, and still retaining some trace of their stratified character, that lie hid beneath the surface of the geologically lowest regions of the State. In making this ideal section, I have taken the sections as given in Canada and in the East Tennessee section. In both of these regions we have great depths of rock exposed. The rocks for some eight thousand feet below the surface are determined from the East Tennessee section. Those from that point downwards are taken from the known rocks of Canada and the northern part of the Appalachian system. It should be understood that below the level marked Potsdam sandstone the section is quite doubtful, although it expresses the best known probabilities of the case: above that level the East Tennessee rocks, with incidental corroboration from the peculiar elevation described by Professor J. M. Safford, at Well's river, near Clarksville, Tennessee, afford what seem to me tolerably trustworthy data for conclusions concerning the underlying beds of Kentucky.

I have already noticed the fact that the well bored near Cincinnati brought up a silicious shaly sandstone from a point about two hundred feet below the lowest level shown in that neighborhood. This corroborates the conclusion that this East Tennessee section is, in a general way, similar to that at Cincinnati, for, beneath the Cincinnati Group, in the Powell Valley, we have a similar silicious shale, known in Dr. Safford's report as the Knox shale. It should be noticed that the East Tennessee section is far thicker than that at Cincinnati. The six hundred and fifty or seven hundred feet of the Cincinnati Group becomes fifteen hundred feet in the section at the foot of the Cumberland Mountains. We may reasonably anticipate a similar thinning of the beds lying still lower in the section in Central Kentucky.

Leaving the doubtful regions lying below the light of day, and coming to the beds which are disclosed in the natural section, we find ourselves in some doubt as to the point where the lowest beds are to be found within the State. The sections at Hickman Landing, on the Kentucky river, and at Cincinnati, both offer us exposures which extend to low points in the series. By a comparison of the sections given herewith, it will be seen that the bottom beds exposed at these points vary considerably.

It has generally been assumed that the beds at Cincinnati are somewhat lower than those at Lexington; but I am inclined to think that a fair judgment on this matter will lead us to very different conclusions. At Cincinnati the beds containing *Isoteles gigas* are found in the bed of the river; and in all my study of these rocks, which has been long continued, I have not found a single specimen of this form above the level of high water mark at this point.

Without attaching too much importance to the indications from a single species, I may say that the occurrence of this same fossil on the level of the city of Lexington, more than three hundred feet above the corresponding height at Cincinnati, has made me doubt the truth of this assumption of the higher geological position of the former place. It will be seen that the series at Cincinnati, beginning with the argillaceous limestones, containing *Isoteles gigas*, is continued by a series of beds containing, among their most characteristic fossils, *Trinucleus* (*n. sp.*), &c. Just above these, and during the time of the disappearance of the genus *Trinucleus*, come fragmentary *Calymene, Orthis testudinaria, Plectambonites sericea*. The higher beds, certain parts of the section lying within one hundred and fifty feet of the Ohio river, at Cincinnati, contain an abundance of *Chætetes*, but always of the *lycoperdon* type, never of the *C. petropolitana* variety. At about two hundred feet above the river *Platystrophia lynx* becomes abundant, and *Strophomena alternata*, which has been represented by rare and attenuated forms—the horizon of the *Isoteles gigas*—becomes very large and distinct. In the Kentucky River section we have no such order of succession of species. The beds, as will be seen by the section, begin by marine, dove-colored, and whitish marbles. These contain no organic remains except the obscure fossils which give the "bird's-eye" look to the mass. After rising through a series of these we come to a level where there is a good deal of shale in rather thin partings. Some of this shown at Frankfort, only a few feet above the top of the "bird's-eye" bed, is of a light green color, apparently owing its hue to a coloring of phosphate of iron. This deposit is analyzed in Dr. Peter's report, and might have some economic value were it not for its thinness.

The next noticeable feature is the occurrence of a bed quite filled with several species of *Orthoceratites*, and containing some specimens of a species of *Conularia*, neither of which have I ever seen at Cincinnati. In no part of this section have I ever found *Isoteles gigas*, or the *Trinucleus* found at the Cincinnati localities, at the same absolute height;* nor in ascending higher do we get into much more familiar associations. The next step upwards brings us into the beds especially characterized by the *Chætetes petropolitana*. Several familiar fossils occur on this level, but they are forms which have tol-

* The term *absolute height* is used to indicate height above the sea level, and is used in contradistinction to relative height, or height above a certain geological level.

erably wide ranges, and they have enough of local peculiarities to enable us to say that they are varieties due to peculiar conditions. As we ascend to the top of the bluff at Frankfort, we come, near the top, into a tolerably familiar assemblage of fossils, which seems on the whole to represent the level found at about two hundred and seventy-five feet above the river at Cincinnati. About the level of the uppermost point in the section at Frankfort we have an important bed, whence have come a number of remarkable fossil sponges. A very curious form, shaped like a candelabrum, briefly mentioned by Dr. Owen under the name of *Scyphia digitata*, seems to occur in this bed, though the several specimens which have been found have never been seen by a naturalist in their original position. This species is only known from the waters of Benson Creek, near Frankfort. I find another species of remarkable form in this level in Henry county (found on the surface). Near Lexington, in what seems to be the same geological horizon, another species occurs, which resembles nothing else so much as a fossil artichoke. This form is very abundant on a small exposure, not exceeding half an acre in area; bushels of weathered specimens could be gathered. No such sponge-bearing level exists in the neighborhood of Cincinnati.

I do not mean to discuss at the present time, in all its bearings, the question of the relation between the Cincinnati section and that at Lexington; for the field work of the Geological Survey cannot be said to have begun in this area. I only desire, in a preliminary way, to suggest that a question exists as to the parallelism of these sections, and that it is an important one for the geology of this district. Either of two conclusions are possible, that the section essentially represents the Cincinnati Group in a geological sense, having been deposited at the same time, or it overlaps it on one side or the other, lying, in whole or in part, above or below it. If the first supposition be true, we must suppose a change of an important kind in almost every element of the section in passing from Cincinnati to Lexington. The other supposition may seem much easier, but we shall find it cannot be well reconciled with the evidence. Near Mt. Sterling, rocks, which seem immediately to overlie the *Isoteles* beds at Lexington, and to be not over fifty feet above them, are in turn overlaid by the beds which we have found within the Cincinnati series, and which are termed the Cumberland sandstone in these reports. Dating downwards from this sandstone, as it is found near Mount Sterling, we must consider the Lexington beds as the equivalent of the highest beds at Cincinnati. The only doubt is as to the existence of a considerable fault between Lexington and Mount Sterling. The beds seem to have no very strong dip in passing from Lexington to Mount Sterling, so that I cannot well suppose a difference of elevation of as much as a hundred feet between the two localities. A careful examination has failed to reveal any signs of a fault between the two points. The existence of a considerable break along the Kentucky river may be regarded as giving a basis of suspicion that we may have something of this kind at Lexington; but there is no good reason for the supposition that there may be a dislocation bringing up the Lexington rocks to a greater height than they would otherwise have had. The work of making detailed sections across this field in several directions, which this Survey now has in hand, will give us the basis for an accurate determination of these points. For the present, it will be best to assume that there is a tolerably accurate correspondence of level between the Kentucky river section, near Lexington, and the section at Cincinnati, the great difference in physical character and in fossil contents being due to the action of some local causes, the nature of which is not well understood, but is probably referable to difference in the depth of the sea when the beds were deposited. On this supposition we will have to allow that the Cincinnati section shows far more alternations in physical conditions than the section at the Kentucky river.

The Cincinnati section gives us many more shales, several distinct, though thin-bedded, layers of sandstone, which are not represented at Lexington, though some few sand layers occur there, and the beds of broken shells which do not occur in Central Kentucky. On the other hand, Lexington has the peculiar upper level of *Isoteles gigas*, the remarkable sponge bed before described, and several other peculiarities which I will not discuss here. There is also an important mineralogical difference. The upper beds at Lexington are charged with saline materials, and give rise to springs clearly resembling in general character the waters which rise at Big Bone Lick from a level beneath the drainage of the country. This is, to my mind, a suspicious circumstance, inasmuch as I have never seen any evidence of the occurrence of these rock waters in the upper levels of the region about Cincinnati. Moreover, the Lexington series of rocks is penetrated in various directions by veins of sulphate of baryta, containing considerable quantities of galena. This galena district does not extend as far east as Mt. Sterling, but lies between a line running from near the middle of Clark county, thence by Georgetown to Henry county, and the line of the Kentucky river. Whether their differences be due to faulting or local peculiarities of deposition, these two regions must be regarded as presenting problems of great interest, which it will be the duty of the Survey to consider.

Taking the Ohio River section as the typical section for the State, and leaving the Kentucky River district out of consideration on account of the doubt which exists concerning its precise position, we arrive at the conclusion that, between the lowest level above the drainage and the Cumberland sandstone, which closes the Cincinnati series, there is a tolerably continuous succession of life from the lowest point seen up to the top of the series. There are certain changes, however, and I have as yet failed to see a single species, except it may be a *Lingula*, which continues quite unchanged from the bottom to the top of the series. The section excavated at the bottom of the channel at Cincinnati seems to mark the top of one association, determined, it may be, by the conditions which made a very argillaceous limestone, intermixed with blue clay, the principal element in the series above these beds at the level of the ordinary high water. Above this point we have a series of massive limestones, very encrinoidal and remarkable for the occurrence of a species of *Agelacrinites.* Above that point there is another series of shales, alternating with limestones, generally with their layers extending up to about two hundred and fifty feet above high water mark. At this point we begin to have a series of arenaceous layers coming into the succession of limestones and shales, and the shales lose, to a certain extent, their blue color, becoming whitish or clay-colored.*

Whenever, in any succession of beds, a series of limestone layer is followed by a sandstone, there is generally a considerable change in the organic contents of the beds, and where, as is often the case, the limestones return again, the interrupted succession of life is rarely restored in its original shape. Most of these beds of argillaceous and calcareous sandstone, the "silicious mudstone" of Dr. Owen, contain some fossils. These are, however, generally small, and are found in no great abundance. Most of the species living in this sea when the deposit of the arenaceous beds began were apparently driven away, and when they returned at all, returned with much altered shapes. Neither in nor above this level have I found the *Trinucleus, concentricus, Isoteles gigas, or Plectambonites sericea.* After it came a swarm of other forms new to the seas of this basin. The history of the details of this change is not yet prepared, but it is sufficient for our purpose of tracing rapidly the physical history of the sediments of this basin to notice the occurrence of the arenaceous level at this point, and also to notice that it makes a considerable organic break in the series. I am satisfied that there are the following distinct organic sections in the Cincinnati Group, as exposed at Cincinnati.

The first of these is the set of very blue argillaceous limestones in which the low-water bed of the river lies, and which

* On page 171 of Dr. Peter's report (vol. 1, new series) will be found an analysis of some of these light-colored or sandy-colored clays, from which it will be seen that they are in marked contrast to the blue lower-lying clays.

extends from forty or more feet below the low-water mark to about fifty feet above that level. The next begins at about twenty feet below high-water mark at Ludlow, Kentucky, opposite the western end of Cincinnati, and extends to probably ten feet above that line. The next extends to the base of the so-called silicious sandstone. The fourth includes this sandstone series, which, with its intercalated limestones, is probably rather over sixty feet thick. The fifth includes the beds from the silicious section to the Cumberland sandstone, which, totally interrupting the Cincinnati series, cannot be called a member of that group. These five sections of the Cincinnati Group are hardly to be called well determined divisions, inasmuch as their geographical extension has not yet been ascertained. They seem, however, to depend on features which should have a considerable horizontal extension. I shall therefore designate them as sections A, B, C, D, and E, of the Cincinnati Group, beginning with the lower division of the formation.

Looking closely at these beds, with a view to determining the history of their origin, we see in the section lettered A sufficient evidence that the deposition was made under circumstances which limited the amount of matter swept from the shores to pure mud. I have never been able to determine an arenaceous element in the rocks from this level. The fossil contents also seem to show that the conditions were generally those of deep water. The principal fossils are tribolites, the exuviæ of which much abound at this level. It is not easy to see which was the principal lime-forming fossil; but I am doubtful if any of the recognized fossils could have furnished enough to make the cement of this argillaceous limestone. The general character of this part of the section shows us that it was accumulated slowly, so that each foot of thickness may well represent many centuries of time.

The next section, which we have termed B, gives us a succession of heavy beds of limestone, the principal fossils being the species of crinoids, which form the essentially characteristic fossils of this level. The same absence of arenaceous material is noticeable here as in the beds below. But there is a bed wherein we have a considerable number of pebble-like masses of an argillaceous material lodged among the fossils in such a way as to convince me that they cannot well be accounted for except on the supposition that they are really pebbles worn from some neighboring shore. We have no reason to suppose that a stone formed of materials similar to the underlying rocks of this district would have furnished any arenaceous matter, so it is not an argument against the hypothesis of a neighboring shore to say that there is no noticeable amount of sandy matter in this level. This section must be regarded as one of the divisions in the Cincinnati Group, where the organic life was most abundantly developed. This development took place in a sea entirely free from currents, and continued without decided change through a period during which many new forms of life unknown to the lower beds were brought into this sea. I am much inclined, from the greater luxuriance of the life, the fewer tribolites, as well as the evidences before referred to, to believe this was a period of comparatively shallow water.

The next level, which is peculiarly that of *Trinucleus concentricus*, is ushered in by evidences of a return to deep water again. The fine clay, which closely resembles in its general character the mud brought up by deep sea soundings, comes again into predominance. The rich assemblage of life fades away for a time, and there are many feet of beds in these layers, showing an exceedingly slow accumulation of matter. The return of the life near the top of this series is gradual, and the assemblage different from that seen before. *Platystrophia* (*Orthis*) *lynx*, *Orthis testudinaria*, and *Plectambonites* (*Leptaena*) *sericea* come in here probably for the first time. All the forms are quite small, there being none of the exuberant life which is so marked a feature in section E.

The change to the level of the "silicious mudstone" of Dr. Owen is sudden, and cannot be ascribed to any other cause save the assemblage of conditions brought by shallow water and neighborhood to current-swept shores. Although these alternations of sandstones, shales, and limestones occupy nearly a hundred feet at its thickest, we cannot regard it as representing a great duration of time. It may be accepted as a general truth, to which exceptions, if any occur, are rare, that sandstones are always more rapidly accumulated than limestones, and that, other things being equal, we may measure the rate of accumulation of any section by the amount of arenaceous matter it contains. The deep sea clays, derived, as they seem to be, from the decay of the free-swimming animals, must accumulate with extreme slowness. Though the rate of accumulation is unknown, we may safely suppose that an inch probably represents the accumulation of very many years. The instant that geological changes bring this region of sea floor into a position where the sandy deposits can reach it, then the accumulation goes on apace, and the rate of growth may be hundreds or thousands of times as rapid as it was during the deposition of the fine clay. It is probably to this rapid accumulation that we owe the barrenness of life so characteristic of most sandstone interruptions in the sequence of limestones. The moving sands smother the living forms of the sea precisely as the wind-driven sands of the land smother forests when they happen to invade them. The smaller, more delicate, and slow-growing forms are apparently the first to be extinguished by the new conditions. The larger brachiopods and other shell-covered animals are tolerably well guarded against this danger.

At certain points in this section there are beds which are, in some regards, like the fine clay of the lower series, but differing from it in being yellow or grey in place of blue, and in containing a distinct, rather coarse grit. They also differ in chemical composition. This mud may also be largely of organic origin, but it did not come as the gentle uniform shower which marks the earlier deposits, but seems to have accumulated rapidly. Many specimens of fossils are carried with it, after the fashion of recent shells in regions where there are great movements of mud from the action of the tides. Near the top of this section we have one strong evidence of the action of currents in the quantities of shells packed together by this action. We can in a fashion measure the energy of their movement by the size of the transported fragments. None of the movements seem to have been able to stir the large specimens of *Platystrophia* (*Orthis*) *lynx*; but the shells of *Strophomena alternata* are often pushed along, turned on edge, and packed together just as I have seen the shells of the *Pectens*, along our Atlantic coast, affected by the tide currents. The shells of the little *Atrypa modesta* also show the same evidences of current action by being heaped together in sheltered nooks. Careful study will doubtless show the direction whence these currents came, but I have not yet been able to get evidence on this point. The beds which would exhibit this action are not valuable for quarry stones, and the fragments which, on the surface of the plowed fields, tell the general story as I have interpreted it, do not, from their detached nature, give the basis for ascertaining the direction of the currents.* The existence of sweeping currents may be regarded as a sufficient evidence, when taken in connection with the quantity of sand and mud, of the shallowness of the water and the neighborhood of a shore, where the detrital matter would be swept.

The next division of the section, that designated here as E, gives us at once evidence of the return to something like the earlier conditions. The clay element of the rocks is again blue and free from much grit. The evidences of currents are no longer to be traced. The organic life which, though favored by the currents, had been diminished by the overflow of sand and mud swept along by them, begins to give evidence of the most luxurious development. In this, the uppermost section of the group, the fossils which have been continued from below, as the *Strophomena alternata* and the *Platystrophia* (*Orthis*) *lynx*, are represented by larger varieties, while the new forms introduced are generally of much larger size than the average of similar forms below this level. The rock is principally a

*The extensive grading work now being done at Cincinnati would give sufficient opportunities for this desirable investigation. I beg leave to commend it to the many zealous and observant naturalists of that place.

limestone, composed, in the main, of the remains of the several species of brachiopods and of corals belonging to the several varieties of *Chætetes lycoperdon*. It is frequently interrupted by thin beds of blue clay, which is essentially the same as that which is found in the lower-lying beds. The large number of brachiopods found in this level give the soils derived from its rocks the peculiarly fertile character which is so prominent a characteristic of them. Certain brachiopods as is well known, generally contain a considerable quantity of phosphate of lime, so that the fertility of new soils may, in a general way, be determined by the extent to which these species abound.

The section we have designated as E has sufficient horizontal extension to make it worthy of a special name, and I venture to designate it by the name of the Kentucky River limestone, from the fact that it is found well developed on the waters of that stream, and has a thickness, varying in different sections, but which may be reasonably estimated at about one hundred and twenty-five feet. At only a few points along the border of the field have I been able to get any basis for estimation, owing to the fact that it is generally only a part of its original thickness that is left.

The passage into the sandstone which closes the series, here designated as the Cumberland sandstone, is quite sudden; a few feet very frequently accomplishing the whole change. I have noticed that the mud coating of the fossils adjacent to the top of the series is more common than at other points above the level of the silicous sandstone or section D. The extinction of life in the Cumberland sandstone is far more conspicuous than in the sand inundation of section D. In the last named section a large part of the organic forms in existence at its beginning continued on to its end; but in this sandstone I have yet to find the first distinctly recognizable fossils. Its greenish color, which is especially characteristic of the rock in its southward extension, along the Cumberland river in Cumberland and the adjoining counties, distinguishes it from every other extensive sandstone known to me. The cause of this peculiar feature escapes analysis, but it is not impossible that it is due to phosphate of iron or some other similar substance; in which case it may owe its color to the organic life of the waters in which it was deposited. The considerable thickening, which takes place as we pass to the southward of the Ohio river, is a tolerably clear proof that the fine-grained sand, of which it is composed, was derived from some source of supply situated in that direction. It is likely that this was an extension of the high land which now forms the northeast corner of Alabama and the western part of Georgia. Many other regions of North America show us the existence at this time, of these conditions which set pebbles and sand afloat at the mercy of the currents of the sea. At this time, in New York, the Oneida conglomerate and Medina sandstone comes in the same general relation to the section of the Cincinnati Group, and may fairly be regarded as the equivalents of the Cumberland sandstone. As there are several of these lifeless sandstones in the section passed through between the base and summit of the Kentucky series of rocks, we will be compelled to give some special consideration to the question of their meaning; but inasmuch as the most extensive and instructive of these beds is found in the rocks which underlie the true coal measures, and come nearly on top of the carboniferous limestone, the question may best be discussed when we consider that part of the section.

Looking back over the numerous changes which occur in the rocks of the Cincinnati period, we are struck with the fact that they all indicate a tolerably continuous deposit of a fine clay, which may have taken place at a more rapid rate at one time than at another, but which never entirely ceased during the period. When organic life, especially molluscan and crinoidal forms, abounded, limestones were formed, more or less argillaceous, according to the relative rate of the two deposits. A rapid accumulation of the waste of the creatures living on the sea floor, giving limestones with little clay, from which there is a series of more and more clay until we have the purest argillaceous beds. In these beds with the most clay there is always more or less lime, showing that organic life has had its part even in the most barren looking of the deposits. The deposits of sandstone seem all to have some trace of the clay in their composition, so it will be reasonably safe to say, that the deposition of clay was a continuous and tolerably equable action, the sand and lime coming in an irregular way from time to time, giving us argillaceous limestones or sandstones. The sandstones being deposited rapidly, contain proportionately little clay.

The theory of the inclusion and preservation of ancient sea waters in our Paleozoic stratified deposits appears to receive some confirmation from the history of these rocks. There can be no doubt that these beds were laid down in the ancient seas much as we find them at present, and that, whenever we penetrate below the general surface of the country, we find ourselves within rocks which show the existence of a considerable amount of just such materials as go to make up sea water. The abundant saline springs in this district of the Cincinnati Group is a matter not only of economic but of scientific importance. I cannot, however, unqualifiedly accept in this case the theory of the eminent chemist, Dr. T. Sterry Hunt, which is to the effect that these salt water springs are fed by the waters of the old seas in an unconcentrated state. The fact that springs such as those at Blue and Big Bone Licks have been flowing for a great space of time, reasonably to be estimated, as we shall see, at hundreds of thousands or even millions of years, is a strong point against this opinion. It is impossible to believe that these streams would not have completely drained all the region from which they take their water supply. If the mere inclosure of the sea water of ancient seas could furnish such a supply, this brine character should be common to the waters of all rocks where it had not been effaced by drainage. Other things being equal, the recent rocks should show it more clearly than the old, for there would have been less chance of their having been drained or worked out than in the more ancient deposits.

The ordinary rocks of the Kentucky series do not hold more than three per cent. of their mass of water when fully charged, so that in a region such as Big Bone Lick the whole of the beds above the springs, which may be averaged at two hundred and fifty feet deep, would only contain about seven feet of this imprisoned water. As these springs cannot be supposed to pour out less than two hundred cubic feet per diem, it is evident, on calculation, that a square mile of this section could only furnish enough water to supply one million days of flow, provided all the water of the section not in chemical combination was completely drained away. And it would require a district about twenty miles square to furnish the supply for one million of years. I am therefore compelled to believe that this region has been subjected to some action which has stored up the concentrated salts of the ancient seas. In the present state of our knowledge we know of no other way in which this could be accomplished except by fencing the region out from the direct sea, and allowing the process of evaporation to carry the concentration of the water to that point where the saline matters are, in part, thrown down on the bottom. This precipitation, it seems to me, need not necessarily have occurred in the beds where we at present find the saline matter. Let us suppose that in some overlying rock, which has since been worn away from this surface, a considerable thickness of sea salts had been deposited there, the action of well known forces would certainly tend to distribute the matter downwards to the underlying rocks, provided the structure was sufficiently open to permit the passage of water, or even the contact of its molecules, throughout the mass. I am inclined to think, however, that the now known salt belts, which exist below the top of the Cincinnati Group, can be explained by the fact that they occur in or about sandstones or other evidences of shoal water. These salt levels are probably the strongest evidence that is furnished to us of the upheaval of this region to the level of the water, on one or two occasions, during the formation of the Cincinnati Group.

The next level above the Cumberland sandstone brings us to the beds which apparently answer to the Niagara Group, so far as can be determined by the few fossils which they contain. This deposit is seen at points from the Ohio river southwardly to the Tennessee border.

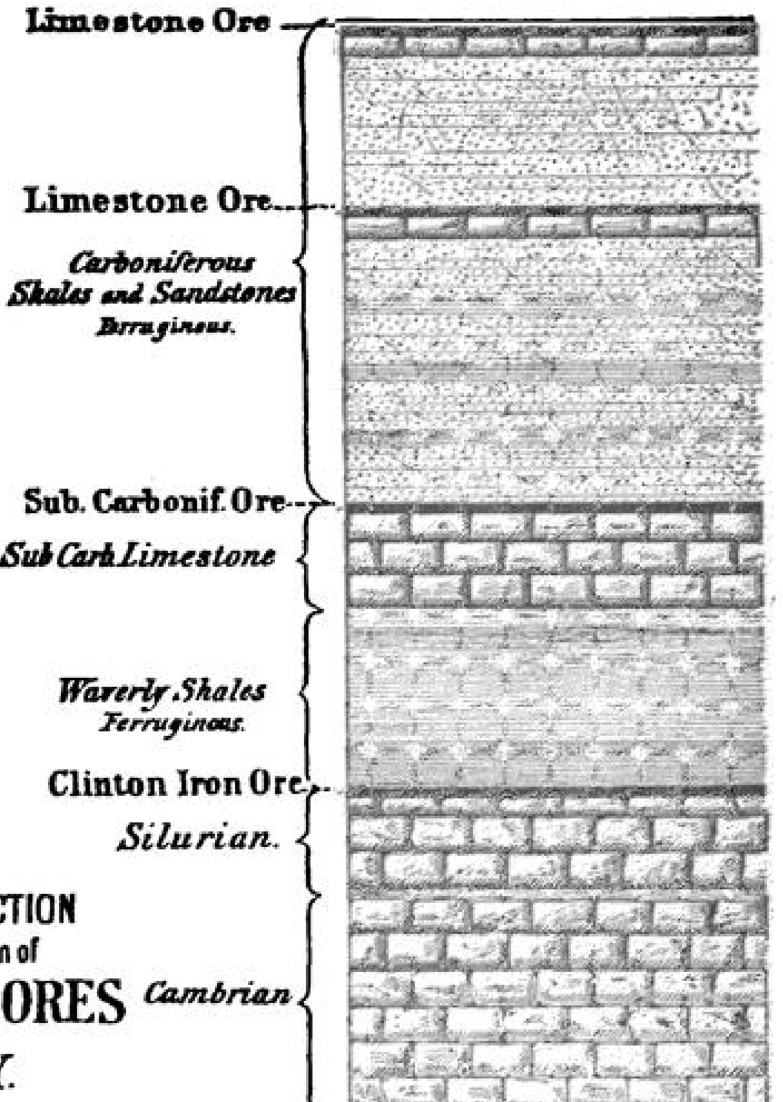
It is evident that this section increases in depth as we pass to the southward, just as was the case with the underlying Cumberland sandstone at Mount Sterling; and to the northward, the great mass of the diminished section is cherty. As we go southward, the cherty structure is greatly diminished. Inasmuch as there is no break in continuity yet observed between the top of the Cumberland sandstone and the top of this so-called Niagara series, we may reasonably regard this mass as representing the whole of the series from the top of the Medina sandstone to the close of the Niagara period, as limited in New York. As yet the amount of work done on this formation within the State is so small that it will not do to make many general statements about it. It seems to show a long period of accumulation, during which silicious limestone and the overlying curious whitish shales were being slowly deposited, probably in a sea of great and steadily increasing depth. Immediately at the close of the Cumberland sandstone, which doubtless shows shoal water, this subsidence sat in. The flinty limestones are the first evidence of deepening water, limestones of this class being generally the product of deeper seas than the limestones destitute of this mixture. The finely laminated clays come next, and give what seems to me good evidence of slow, deep water deposition. This deepening seems to have culminated in the succeeding formation, as we shall see hereafter. In East Tennessee the beds are very much thicker than in Central Kentucky, and contain a large amount of coarse sediment, principally thin-bedded sandstones, and at the very top, including a true conglomerate, which, though possibly rather local, yet marks distinctly the extreme nearness of the shore.

The most remarkable feature in this formation is the presence at various points of extensive deposits of iron ore. At its upper limit this feature is by no means peculiar to Kentucky, but occurs at about the same level all the way from New York to Alabama. Not that the iron ore is found at every point, but there is probably not fifty miles along that great distance where it is not found in a noticeable development. Wherever this deposit occurs it is in the shape of a bed of fossils, which undoubtedly once constituted something like a limestone or a calcareous shale; the iron having, however, in most places, taken the place of the original material of the fossils so as completely to replace the lime. The exceedingly important question of the origin of iron beds of this general character receives some light from a consideration of these deposits, which, occurring about the level of the Clinton limestone in New York, have commonly gone by the name of the Clinton ores. It is evident from a study of the varied conditions under which the beds of this section were deposited, that if the ore was laid down at the time when the beds were formed, then it must have been deposited under the most diverse conditions imaginable. In New York it must have been deposited in a shallow sea, near the shore where limestone was forming; in Pennsylvania, under similar conditions; in East Tennessee, in a shore line where rapidly accumulating sandstones formed a prominent feature; in Kentucky, at the bottom of a deep sea, probably at a considerable distance from the land. It is evident that this view is not tenable. Following the safe rule of modern geology, and testing the operations which have gone on in the past by the actions of the earth at the present day, we may safely say, that a deposit of iron under such circumstances is impossible. There is no known way in which iron can be laid down in the form of marine beds in the deep sea. Some small quantity of iron is contained in many sea-weeds, and, doubtlessly, where they continually decay on the same spot (as has been suggested by Pumpelly*), there may be an accumulation of iron, probably in the shape of a shale containing some of that metal distributed through its mass. But these thick accumu-

*See Reports of this Survey, new series, vol. II, page 318 *et seq.*

lations, where in some cases more than sixty per cent. of the mass is iron oxide, cannot be thus accounted for, and the only way to explain them is by supposing that, in some fashion, we have had a concentration into one plane of a quantity of ferruginous matter which had originally been deposited either above or below that level. As the methods of this action are not only of great scientific but of exceeding economic importance, I have given the subject a good deal of attention in the field. The various ferriferous levels of Kentucky afford us a considerable variety of conditions, which may be grouped, in a general way, into three classes, viz: 1st. The limestone ores, where the conditions show us that the iron has replaced carbonate of lime; 2d. The nodular and black kidney ores, where carbonates of iron are grouped in segregated masses on levels where there is no evidence of limestone having been accumulated; and 3d. The pipe or stalactitic ores, which are clearly superficial beds worked out from older deposits.

The first of these classes, that to which the so-called Clinton (which I prefer to call the Silurian) ore belongs, is represented in the State of Kentucky by the bed formed on the top of the Sub-carboniferous limestone, and by the bed in the coal measures known as the ferriferous limestone. There are other and local cases, but these three are the only wide extending beds of this character. In each of these cases there is a thick section of shales and thin sandstones presumably deposited in marine conditions, lying immediately over the beds in question. In the Silurian ore and in the Carboniferous ore, the character of the underlying beds makes the supposition that the iron deposit was derived from below quite impossible. It is, therefore, to the overlying beds that we must look for the supply. The fact that these beds are the product of marine deposition makes it likely that the iron was originally carried down in the structure of the depositing seaweed, or precipitated by the action of decaying organic matter, as has been suggested by Dr. Hunt. Then we may well look to that shale as the source of a considerable supply of iron. It is easily seen by analysis, or by examining the springs that originate within the Ohio shale, that there is a considerable store of iron in that mass. The same evidence may be had in the case of the marine shale section, which, over a large part of the State, lies immediately on top of the Sub-carboniferous limestone. As all rock masses, save, possibly, at depths below the range of man's observation, are injected with water, it is not unreasonable to suppose that heavy matter, such as the oxides of iron, may be slowly and steadily working downwards through the menstruum of water. It is evident that this action must be going on whenever in any region the drainage level has cut down so as to drain the beds which happen to underlie the shale in question.



DIAGRAMATIC SECTION
showing position of
LIMESTONE ORES
in
KENTUCKY.

In the accompanying figure, it will easily be seen that in the case of the part of the section above the level of the drainage, the downward working of the contained iron is a matter of necessity; and if we acknowledge that the lime carbonate of the limestone has any special power of arresting the moving iron, it follows of necessity that a deposit will be made at the point of junction of the lime and the overlying shale in sandstone, from which the iron is working downwards. It is, however, not so clear that the iron contained within the shale which lies beyond the drainage, is under similar conditions of downward working. As far as the movement of the iron towards the limestone is the result of the actual current in the water, brought about by the drainage outflow, of course it would be wanting at the points represented below the drainage; but the downward working may be due not alone or in any great part to the drainage movement of the water, but rather to the *osmose* movement, which leads to the equalization of matter through the whole of any fluid mass in which it is contained. I am not aware of any experiments to show the distance to which this movement may extend, but it seems a necessary consequence of the law of *osmose* action that the process of equalization should go on through the whole of the section where the particles of water run in contact, the only question as to its efficiency being the time required to accomplish the given result. This is by no means an abstract question, but one which most intimately connects itself with the future interests of the country. Long before the fuel resources of this country can begin to be exhausted, the iron ores of the superficial regions, and those known to be rich at greater depths, will have been exhausted The problem is the same for the world at large—the resources of the one absolutely necessary metal, the material without which we cannot imagine civilization to keep its place, are not nearly as satisfactory as the resources of heat and light, those other factors of civilization.

There seems a great chance that, long before fuel is exhausted, the available iron of the world will be wasted into the sea or the soil. If, however, we can prove that these Silurian and other limestone ores are continued beneath the drainage of the districts where the beds which have formed and contain them are found, we enormously increase the possible iron mining area. The rich iron district of East Tennessee may then be continued beneath the overlying rocks, and occupy a large part of the area covered by the Carboniferous and other superior beds. If we could prove that only one tenth of the buried rocks of this level and of the Sub-carboniferous limestone are covered with workable iron ores, we would thereby probably add more iron to the known store of North America than is included in all the deposits which have as yet entered into our considerations. The only way in which this matter can be definitely decided is by borings made quite through these basins at a number of points where the rocks are clearly below the drainage level.* To determine the existence or non-existence of this iron ore beneath the drainage, borings should be made at selected points along the Cumberland Mountains. The great north and south extension of the ore on that line would make it nearly certain that it would be found beneath the drainage, in case its formation was not due to the drainage action itself, which I cannot easily believe. I should consider the failure to find the deposit at a very few borings made along this line, and not necessarily more than three to five hundred feet deep, as sufficient to determine the matter. I do not propose at this time to undertake to discuss the general question of the genesis of iron ores; so with this reference to a possible explanation of this special deposit I shall pass again to the question of the character and history of the rocks in which it is found.

* Nothing better illustrates the importance of a continued scientific observation of any State than the fact that in this State, during the various borings for salt and oil made in the last half century, abundant opportunities have occurred for the most complete determination of this point; but they have been entirely lost through the want of some system of State inspection of its mineral districts. To repeat these borings on anything like the same extended scale would, I estimate, cost not far from one million dollars. I have no doubt that within a century this sort of exploration will be repeated with equal cost, perhaps not in search of the same things, but with some other quest which could be fully answered by an examination of the borings of these hills, had they been carefully collected and preserved. One per cent. on this capital would maintain a watch on all the underground operations of the State, and thus continue the work of a geological survey after all the surface indications had been completely investigated.

This so-called Clinton iron bed may not be unusually found at the top of the Silurian section. At many points it seems to be nearly, if not entirely, absent. Far too little study has yet been given to the extension of this ore deposit to make it certain just how generally it is to be found. Owing to the softness of the overlying shales, the top of the series and its contained beds are not often clearly seen. It will be our especial object, in the future work of the Survey, to get all possible information on this point. At some points the passage into the black shale shows several alternations of silicious beds with the shale. Generally, however, it is pretty abrupt, and we pass quite at once into the Ohio black shale. This remarkable formation, by far the most inexplicable of all the beds of this country or in Europe, is more nearly limited to the Ohio Valley than any other of the formations which have as yet been found within its basin. I therefore propose for it the name of the Ohio shale. I am aware that it has already been termed the Huron shale or the Huron beds; but this name is not satisfactory, inasmuch as it is likely to be confused with the Huronian formation, when the name of this great lake was first connected with a system of rocks. The name would be, moreover, quite out of place applied to beds which have very little connection with the region of that lake. Probably more than five eighths of the Ohio basin lie over this formation; over some tens of thousands of square miles it constitutes a large part of the surface rock. On these accounts I have deemed it best to give the name of the Ohio shale to this formation.*

With slight local differences, from point to point, this formation consists of a tolerably uniform mass of thin-layered bituminous, petroleum-bearing shale, accumulated in a very uniform succession to the depth of one hundred feet or more. The inorganic matter is a fine mud, such as we have deemed elsewhere to afford evidence of deep sea at the time of its deposition. The organic matter is so far changed that it is not easy

*I have concluded, in the naming of local beds, to follow the plan of naming them after the river valley where they are most abundantly developed.

to determine whence it came. In Kentucky, along the Ohio, near Vanceburg, in the workings made a number of years ago, when the shale was distilled for coal oil and paraffine, there were a number of jaws of fishes and other parts of the same animals found imbedded in the shale in a disorganized state, as if the whole animal had not been buried at the same place. At various points over the southward extension of this formation I have found similar remains, in rare cases scattered throughout the whole section. The only other fossils found have been remains of two or three species of brachiopods, allied to the Lingulas, and which seem to have been very small members of the group. None of these fossils give any clear indications as to the fresh or salt water character of this deposit. The fishes at no time in the earth's history have left evidences which would make it certain in which conditions their lives were led, and the brachiopods of the group of Lingulas are, as I shall hereafter endeavor to show, by no means certain indications on this point. Considering the very great extent of this formation, it is not unreasonable to suppose that the deposition must have taken place on the sea bed, and the absence of all coarse detritus, such as coarse sand or pebbles, the general evenness of the mass, and the want of all the fossils which generally characterize the shore line, is tolerably conclusive evidence that the beds were formed in deep sea far from the land.

The important fact that this formation, unlike the Cincinnati Group, the Niagara section, the Sub-carboniferous lime, and the Conglomerate, does not materially thicken as we approach the Unaka Mountains, points to the conclusion that it derived no waste from that section. Its thinning as we go towards the Gulf of Mexico, while the Cumberland sandstone, the Conglomerate, and the Sub-carboniferous limestone all thicken that way, points likewise to the conclusion that the land area, whence the mechanical element in the composition of this shale was derived, lay to the northward of the Ohio; the region to the southward being pretty generally submerged at the time of its formation. The extreme ease with which shale is eroded makes it doubtful how wide was its original extension. The absence in its structure of distinct marks of nearness to shore seems to me convincing that we have nowhere found its shore line. If it was followed, as we shall see reason to suppose hereafter, by a sudden and tolerably complete return to shoal water over a large part of the area occupied by its deep sea, then the marginal parts of the deposit, being left unprotected by subsequent accumulations, would have quickly faded away before the erosive forces, as it now disappears whenever not sheltered by harder overlying beds.

The large amount of petroleum which is always contained in this set of beds may well excite our astonishment. Something of the facts are given in the economic section of this report. It remains to look a little to the theory of its production. It is evident, in the first place, that this matter must have been formed where we now find it, for it could not have been derived from the deposits which lie above or below its level. The series of the Cincinnati Group and the Silurian, properly so-called, have, throughout this section at least, no considerable amount of such matter in their structure, nor does analysis teach us that their organic contents could ever have yielded a great store of carbonaceous matter. The overlying rocks are arenaceous, and were doubtless made in seas where the development of organic life was relatively very small. Within the Ohio shale itself the beds furnish us little else save fish remains; and I was, at one time, disposed to believe that to these animals we must look for an explanation of this organic matter. It seems to me now, however, that the suggestion of Dr. Newberry is more likely to furnish the true solution. His hypothesis is, that the region was the seat of a great sea-weed deposit, being on the floor of a sort of Sargassum or Sargasso sea, such as now occupies the central part of the North Atlantic. The only difficulty is to see how any known form of sea-weed could have formed such a mass without leaving some distinct remains of its structure. The present forms are those which would be likely to make frequent fossils in mud of this consistence. Some vague markings are to be found there, but nothing like the distinct marks which, in earlier and later formations, as in the so-called "Caudi Galli," of the New York series, and of the Waverly sandstone, mark the presence of these organic forms. It is not unlikely that the deposit is the result of long-continued slow deposition, wherein sea-weeds, fishes, and possibly many invertebrate animals, contributed to the waste. The presence of many large and vigorous fishes goes to show that they must have had an abundant invertebrate life for their support. The absence of the fossils of the softer animals may be explained by the want of sufficiently rapid accumulation to insure their burial.

The conditions under which deposits of organic matter form hydro-carbons are not well understood. I am inclined to think that we cannot reasonably suppose that the change took place long after the deposition of the beds which form the shale. The conditions of the beds that lie below the black shale, in the Cincinnati Group, or in the Niagara section, show that there has been no great invasion of heat since the beds were deposited. Clays, which change greatly under a heat of one thousand degrees of Fahrenheit, are apparently exactly as they were left by the sea, and beds retain their marine salts just as when they were deposited. Any great access of temperature in this deposit of the Ohio shale would have been attended by an almost equal rise of temperature in the coal beds which lie within a few hundred feet above; but these coal beds are free from any evidences of distillation or other consequences of heat. We have already seen reasons for supposing an erosion of some three or four thousand feet of strata from this section; if we could reimpose this section, we should probably bring up the temperature of these rocks, by the rise in the isogeothermals, or lines of equal internal heat, about sixty degrees, granting that the rate of increase in temperature has grown less after the rate indicated in the calculations of Sir William Thompson.

We are not able to suppose that the accumulation of strata could have elevated the temperature above the point of boiling water. The hypothesis which may be formed to account for the formation of this coal oil must take into consideration the impossibility of its generation at another point and its removal to this set of beds, and the impossibility of supposing that it has been, in any way, the result of high temperatures.

I have already referred to the large results obtained from the distillation of this shale. (See biennial report in this volume.) It should be noticed that these determinations are based not on the substance from points where it has been excluded from weathering, but on material taken from points above the drainage and near bluff banks, where it was exposed to thousands of years of slow decay and washing. Wherever I have been able to hear of borings below the level of the drainage, the mass has been found completely saturated with the oil. At many points the progressive leaching of the mass is readily determined. The outside surface, and within for several feet, may be quite deprived of its hydrocarbons, and as we go from this face there seems to be a progressive increase in the quantity of those matters. On all these accounts I feel justified in saying, that the normal state of the deposit is that of complete saturation with coal oil.

The equivalency of this shale with the deposits in New York has been a matter of much discussion. The section in East Tennessee, when compared with those of Kentucky and New York, has satisfied me that the Ohio shale includes everything from the top of the Oriskany sandstone to the top of the Chemung.*

In East Tennessee the Silurian and Devonian sections are still faintly recognizable. On top of the evident Clinton and Niagara fossils, some beds are found containing *Leptocœlia* of a species closely allied to, if not identical with, the characteristic species from the Oriskany sandstone. The other organic species of this group ally themselves with those from the Oriskany sandstone in many important regards. Above these beds come a set of barren beds, thirty or more feet in thick-

* This question I hope to discuss in the Memoirs of the Survey, for which purpose data concerning the Ohio shale are now being collected. A brief and rather unsupported statement is all that can be made here.

ness, with a considerable conglomerate bed, which, being deposited in patches, is strong evidence of shore or shallow water conditions. In Central Kentucky this Oriskany sandstone is merged in the Niagara series so completely that I have not been able to separate it or to find its characteristic fossils. This evidence satisfies me pretty well that this black shale does not include the beds contemporaneous with the Oriskany sandstone. In East Tennessee the Ohio shale comes immediately on top of the beds which I believe to represent the Oriskany sandstone. In Kentucky it is found immediately on top of beds which, certainly, are not higher than the Oriskany. In both these cases the surfaces are entirely free from any symptom of erosion. Therefore, allowing that these beds have not been eroded, it follows, of necessity, that the black shale in this section, as far as may be judged from this evidence, includes all that follows the Oriskany sandstone up to some point yet to be determined.*

Although there are some argillaceous and slightly calcareous bands in the black shale and one or two silicious layers, I am unable to make any satisfactory decisions as to its origin. I believe there is no section in our beds representing anything like the amount of time which it requires, and having anything like the uniformity of structure possessed by this Ohio shale. When, therefore, we find evidence that the beds which immediately overlie the black shales belong to a section later than the last of the lower rocks in New York, that, in a word, we have passed in it through the whole Hamilton period, through the whole Chemung period, and possibly through a still later time represented by the Catskill Group, we are driven to suppose that this was a region which had no share in the disturbances which took place in New York. The easiest way to account for this uniformity of conditions is to suppose that it

*I am disposed to insist on this method of determining equivalency notwithstanding its serious consequences. It is always to be remembered, that as long as a region is beneath the sea it is always receiving some sediment, however little; so if at any point we should find Cincinnati Group fossils, and then a few feet of shales followed by Tertiary beds, the whole well exhibited, with no evidence of a break by erosion, we would be logically compelled to assume that this thin section represented all the vast period of the earth's record between these two horizons.

was buried deep in the sea when the changes of level took place, which may have brought great modifications at the shore. Whenever the Atlantic coasts rise and fall suddenly, by say five hundred or a thousand feet, prodigious changes are necessarily brought about in the beds which are forming, new fossils are brought to the area, and other kinds of sediment laid down. But in the deep sea these changes probably bring no break in the uniform succession of events. Its Sargassum sea will keep about the same place, and it certainly is a rare chance that anything occurs to mark the change of level in beds just beneath its surface.*

I am inclined to accept Dr. Newberry's conclusion concerning the equivalency of the beds, termed by him Waverly, which immediately follow the black shale. He gives them a place at the base of the Sub-carboniferous rocks, and their fossils certainly bear out this classification. In Kentucky this section varies from about six hundred feet thick, along the Ohio, to rather less than half that amount, where they are disclosed along the Cumberland river in Clinton county, and to about two hundred feet at Cumberland Gap. Wherever found within Kentucky, its history is evidently that of a rather shallow water formation, deposited at a period when the transportation was by gentle currents, without the violence which seems to have affected the ocean movements in this region at a later time. As we go southwards this formation becomes less distinctly sandstone. The clay element increases, though this is generally silicious, the formation giving little trace of the carbonaceous character common to the Ohio shale and to the carboniferous shaly beds, save at one point near the Ohio river. In East Tennessee, twelve miles north of Cumberland Gap, it is still very sandy, the beds being quite thick though rather incoherent. It abounds there with the Spirophyton or "Caudi Galli," which is abundant along the Ohio river. At Cumberland Gap we begin to get many beds of dense silex or chert, but the larger part of the mass is still a very silicious,

*See Vol. II, new series, of these Reports, p. 327, for some matter from the pen of Professor Pumpelly, which has an important bearing on the question.

indurated clay shale. Forty miles further south, near Jacksboro, Tennessee, the amount of cherty matter is greatly increased, so that the mass well deserves the name of "Silicious Group," given it by Professor Safford in his Geology of Tennessee. This rapid change is apparently attended by a certain shrinkage in the thickness of the formation.*

The same change, though carried to a less extent, occurs along the Clinton county section, where the presence of silicious matter is also a conspicuous feature in this formation. The greenish color in the beds of this age is a striking feature at many points, and reminds us of the tint observable in the Cumberland sandstone. The great amount of these arenaceous deposits makes it pretty certain that these beds of the Waverly series were deposited with great rapidity. They probably do not represent more than a very small fraction of the time represented by the beds of the black shale. Sand deposits are necessarily made with rapidity. They demand for their formation the energetic action of the sea upon a great extent of land. It is on this account that they are peculiarly the product of periods of rapid change of level. Along the Atlantic coast of the United States we see the result of these changes in a striking manner. There has been a general rise of the whole of that coast since the middle tertiary; and the retreating sea has carried back with it a great quantity of sand. From each of its great invasions the sea bears back a rich booty in the sands worn from its receding shores. During the period when the sea is gaining on the land the forming sands do not work seaward. Their limit is made by the depth at which the currents cease to have a sweeping power, and with a sinking shore, these are continually working in towards the centre of the land. When the sea goes back it is with full hands, and the sand-beds work out over the sea bottom with great

*I am aware that I differ from the able geologist above mentioned in my opinion as to the age of these cherty beds of the region from Cumberland Gap westward. I shall endeavor to discuss this question more closely hereafter; but for the present I can only express my respectful dissent from the opinions of my learned friend on this matter.

rapidity. The currents, then, have all that they can carry away.

Along the shore of Massachusetts and Connecticut the sands washed from the newly risen shore, and scattered far and wide over the sea, make a deep bed, reaching on the average nearly two hundred miles from the land, and having a depth, probably, averaging over fifty feet. All this vast mass is the product of a short time of carriage and deposit—so short that it is difficult to exaggerate its brevity in a geological sense.

This interesting question of the action of a retreating sea cannot be discussed here, but I trust enough has been indicated to show that there are reasons for believing sandstone series like the Waverly to be evidences of a general uplifting of the region where they were depositing, and a consequent sweeping of a long forming store of sand out into the sea. The question may naturally arise, what became of the coarser products of this erosion—where are the gravels and boulders which were encountered by the ancient seas? The evidence to give the answer is not wanting on our own shores: these coarser materials are either ground up on the shores, as the seas move over the land, or are to a great extent left behind in the movement, to be in time worn again and again, until they are finally quite reduced to the size when they can be carried by ocean currents.

Although the Waverly period seems to mark the steady uplift of this part of the continent, it is not certain that the sea bottom was bared over any great area at its close. Along the Ohio river there is some evidence of land, perhaps, to be found in the fire-clays occurring near its top. The idea that these beds are the exhausted soils of old forests has much to commend it. There is no other simple way of accounting for the formation of such deposits. If forests ever flourished in this region, subsequent waste has destroyed all trace of their existence. A careful study of these Waverly beds is yet to be made, and several years' work will be necessary to their full elucidation. These are only a few general conclusions of value, which may be stated with some confidence. The absence of all pebble deposits is tolerably safe evidence that the shore was not extended across this State during the upheaval of the Waverly period. When this sand was formed there must have been enormous stores of gravel and boulders, and some part of this matter must have worked along the shore, if they were ever near here. The absence of such materials is presumptive proof of the distance of the shore of the main land.

At the close of the Waverly period this unstable region seems to have begun once again to subside; and with this subsidence comes an utter change in the physical and vital conditions of the sea. The complete interruption of the movement of sands is the first evidence of this change. With it comes the rapid development of great quantities of marine life, differing from, though closely allied to, the life in the beds below. The organic life showed its vigor in the many species of crinoids and brachiopods of large size. With the change this life rapidly developed most of the forms, gaining considerably in size and vigor of growth.

The enormous development of organic life of relatively high forms, and the rapid specific change of that life, serves to show us that the Sub-carboniferous limestone was not formed in a very deep sea; at the same time the far-reaching character of the deposit and its great thickness negatives the idea that it could have been formed in very shallow water. As we trace it to its end over the Ohio line, it has been supposed that it had its shore there. I have failed to find good evidence of this, however, and am disposed to attribute something of its absence to the wear that came after the final uplift, when the Carboniferous limestone became the basis on which the coal measures or their lower member, the conglomerate, was deposited.

In a general way this Sub-carboniferous limestone may be said to extend from the Ohio river westwardly, or rather northwestwardly, to the Rocky Mountains, where its thickness is very great, and southwardly to Alabama, and to have its eastern border against the ancient axis of the Appalachian chain. Except the rocks of the Cincinnati Group, it is the most extensive series of limestone known in our American section; indeed, at this time, throughout the world, there seems to have been a period of limestone production unequaled in its area and activity in all the earth's history. Not only in this country, but in Europe as well, a period of extraordinary limestone accumulation was begun at this time. This singularly active accumulation of limestone is doubtless to be, in good part, attributed to the existence of species capable of rapidly depositing limestone from the waters of the sea. Along with this, probably, went that gentle subsidence of the sea floor which is calculated to prevent the coarser inorganic waste of the land from invading the regions of the sea when deposition of an organic kind is going on. I am much inclined to think, however, that there was at least one other cause, which contributed to the formation of this great limestone deposit. The simultaneous formation over wide areas of such great deposits, formed under circumstances which afford tolerably good evidence that they were rapidly accumulated, leads me to suspect that there must be periods in the history of the sea peculiarly well fitted for the life of limestone-secreting forms. If, as I am inclined to believe, the amount of surface varies considerably in different geological periods, then it may well follow that the amount of calcareous matter in the sea, which is derived from the waste of the land by rain-fall, may vary considerably.

Taking the common estimates of rain-fall, and the usually reckoned depths of the sea, it would require about ten thousand years for the whole of the water of the sea to fall upon the land. This is really a rapid rate of movement in a geological sense; and in case anything happened to extinguish certain races fitted to recover this lime and related matters from the sea, there might be a considerable gain in these materials until some other form of life, fitted to discharge this matter, came upon the scene. We do not know in any other period an occasion when the discharge of carbonate of lime from the sea was so rapid and long-continued as in this formation. That the formation of a large part of the limestone was very rapid is proven by the frequent great size of the organic masses which compose it.

In the case of reef-building corals, which seem to be the only members of the group capable of making extensive deposits of limestone, their development seems limited to the localities where they can be exposed to a sweeping current; in such positions the corals may occupy a region not over a few miles wide and generally only a few hundred rods in transverse extent. It would seem that, in passing over this distance, the water becomes so far impoverished that it can no longer sustain a vigorous growth of corals.*

In the case of the crinoid-covered sea floor the growth was not limited in any such fashion, but spread far and wide over an area of certainly hundreds of thousands of square miles, in all of which there is only the least trace of matter of an argillaceous or arenaceous character. I doubt if there is anywhere within the present seas, away from the coral reefs, any such great accumulations of limestone going on as this affords us, or if our present seas could supply the needed conditions in the way of calcareous matter.

The rapid growth of these beds is also, in a measure, shown by the considerable thickness of the several layers. In no other of our unaltered limestones do we find thicker beds. This is in part, certainly, owing, as I have already suggested, to the fact that the animals which formed the large part of this limestone grew, and to a considerable extent decayed, in an upright position. I am inclined to think that, if we could restore the old crinoid groves to the sea floor, and study the conditions, we should find them much as follows: the crinoid stems, thickly dotted over the sand bottom, where the decaying stems and branches, and the numerous molluscs, made a bed of already hardened limestone; those still living, would rise from two to four feet above the surface, and spread their

* This point should be determined by careful examination of the quantity of different substances contained in the water before and after it had passed across the reef.

arms some half a foot when expanded; the dead crinoids would quickly drop their heavy heads, but their stems would keep standing for some time, and were often half buried by the rapid growth of waste before decay brought them down to ruin. The molluscs, the corals, and other minor elements of the life, do little more than fill in the interstices.

Many of the beds accumulated on these old sea floors are clearly the product of other conditions. The very fine dolomitic limestones of Kentucky seem to have been made by an impalpable mud, in which few organic forms have ever been buried in a fossil state. I am not satisfied as to the history of these masses, but I am inclined to think that they mark a part of the time when the sea floor was depressed to a great depth—so deep as to exclude these forms of life, and bringing the sort of conditions now found in the deep sea region of the Atlantic.

The variations of thickness in this deposit in Kentucky are considerable. Passing to the southward, the thickness is tolerably proportionate to the distance from the Ohio river, though in the region below Louisville it attains a considerable depth. Its thickness at Cumberland Gap is about 450 feet. At the Mammoth Cave about three hundred feet are seen, and a boring for oil is said to have shown five hundred feet, and the boring stopped in this rock. In Northern Tennessee it is said to obtain the thickness of 900 feet.

It is quite natural that a limestone should gain in thickness towards the southward. It is more than probable that the temperature conditions, as well as the influence of currents in bringing supplies of fresh sea water, which we know to be most efficient means of aiding the growth of all marine invertebrates, were more effective the further south we go. To this cause I attribute also the gain in thickness of the Cincinnati Group, which passes from about seven hundred feet, on the Ohio river, to fifteen hundred feet in the region about Cumberland Gap.

So far as my observations go, the Sub-carboniferous limestone is divided in Kentucky into but two distinct members.

The lower or St. Louis is the massive and especially cavernous element. The upper or Chester begins to show a change from the conditions which brought about perfect freedom from arenaceous and argillaceous matter, and has its most important physical character given it by the return of the alternating sandstones and shales which form such a sure mark of the approaching shore. The Chester Group may be regarded as beginning with the first of the sandstones and ending where the limestone ceases.

There is no trace in Kentucky of the Carboniferous shore line, at least until we come to the later stages of the Chester. In the northwest and west there is reason to believe that these rocks were deposited nearer a shore; this is shown there by their less continuity and the greater predominance of the arenaceous element in their composition. To the south of Kentucky, at least about Cumberland Gap, this arenaceous element in the Chester becomes less conspicuous than it is even in the Mammoth Cave district; hence, I conclude that, as the first named region was more remote from the Laurentian shore, it may be that there was another shore line in the North Alabama section; but this last named district I have not examined in person. The immense and long-continued erosion of the period immediately following the Sub-carboniferous limestone, the results of which we see in the conglomerate or the millstone grit, probably wore away all the shore line deposits of this period, as well as the exposed shores of many of the older formations. Before the limestone-making creatures had been entirely driven out of this sea, there is abundant evidence that the carboniferous vegetation was already occupying the neighboring land, and ready to occupy the sea floor as fast as it was bared by the raising of the land.

In the upper Chester there are one or two beds of coal which sometimes attain to about a foot in thickness, and are found over the western coal field at almost every point where the limestone is exposed. In the eastern field this sub-carboniferous coal seems to be quite wanting. In the western coal field, the transition from the limestone appears to have been much more slowly completed than in the eastern section, there being, in the Edmonson coal district, three or four distinct though thin beds of marine limestone within one hundred feet above the lowest or Chester coal, each marking a return of the sea over the land in the successive alternations of movement. Some trace of this alternation, though in a far less degree, is seen in the coal measures of Northeastern Kentucky. About Cumberland Gap, however, the limestones show no such return to marine conditions. When the limestone-building ceases, which it does pretty abruptly, it does not reappear in the subsequent two thousand feet of strata. I am inclined to attribute this, in part at least, to the far more considerable amount of detritus, which accumulated at the last named region, where the conglomerate is much thicker than it is in the Edmonson district, or in the northeastern part of Kentucky. This section, probably, remained in rather deep water long after the other regions mentioned had been brought to near the sea level. When this process of uplifting had ended the Sub-carboniferous period, by extinguishing the life which made that time so conspicuous, there seems to have been a time of comparative steadiness, during which the land retained its position with reference to the sea. Although local variations in the deposits make it tolerably difficult to make general assertions concerning the beds that succeed the Sub-carboniferous limestone, it is doubtless usually true that the Western Kentucky section gives us generally sandstones more or less dense, and but little shale. The sandstones and the shales seem to be fresh or brackish water deposits. In Eastern Kentucky, however, the amount of shales is relatively much greater than in Western Kentucky. Here, too, these shales were apparently formed in fresh water, and the conditions were sufficiently favorable for the formation of two or three beds of coal, within about one hundred feet from the top of the limestone. These beds of coal are about the most persistent and trustworthy of all the beds known to me, in Kentucky. These coal beds show very distinctly the uniformity of the conditions—the absence of all violence of a general as well as of a local character. At Cumberland Gap, those shales that lie just above the limestone, contain no coal or other signs of plant life, and are very sandy, being in places scarcely more than soft sandstones.

In these conditions of tolerable uniformity the first stage of the Carboniferous period was passed. As this period is set apart by its physical and vital conditions from anything that came before or afterwards, it deserves a special designation. I shall, therefore, in order to indicate my sense of its distinctness as a period in the history of the Ohio basin, as well as to avoid periphrasis, give it the name of the Kentucky shale. This name is especially fit, inasmuch as in the region about the head waters of the Kentucky river, we have the best exemplification of the Sub-conglomerate coal series which has yet been examined. These geographical names have some objectionable features; and when the identity of time and identity of conditions in two regions can be established, it is doubtless proper to retain one name for the two formations; but in all cases when the identity of time is questionable, or when the conditions were entirely different, I think a local name warrantable and desirable.*

In point of fact we know little about the exact correspondence in age of formations; so the less we do in the way of question-begging in the use of our terms the better. Like the other local names which we have adopted for our Kentucky rocks, it asserts a place of occurrence and something of the physical character of the bed, leaving the question of its precise horizontal equivalence to be determined hereafter.

It is quite evident that the exposure of the land was long continued, and that the area above the water level, in Western Kentucky at least, was considerable. On the lower waters

* It should be noticed that there are two elements to be denoted by a name such as Bath Oölite—the time when it was formed, with relation to the general history of the world, and the physical conditions existing at that place at the time when it was laid down. If we find at another point a series of volcanic deposits, a deep sea shale or recent plant beds, which can be identified in age, with the above named formation, it would not be reasonable to give them the definite name of Bath Oölite, or even Bathonien, in the generalized nomenclature of D'Orbigny.

of Nolin river, we have distinct evidence of the excavation of a large river basin in the rocks of this Kentucky period, after some of the coals were formed. Into this basin the moving pebbles of the Conglomerate or Millstone Grit period were poured, filling it up to a depth of two hundred feet or more. This section compels us to suppose that, after the formation of the Kentucky shales, there was a period of degradation, when running water cut down river beds as deep as those which now traverse the country.

There have been so few openings made into the rocks of this age in the way of mines, that we are not able to say whether this sort of erosion is common or not; but this is the only case that has been observed. The sectional area of the excavation is about as great as we could expect in the case of a stream of the size of the neighboring Green river, which, as is well known, drains a considerable area. The course of flow of the stream is not clearly marked, but the excavation has its axis in a northeast and southwest direction. There is enough known of the structure of the rocks of this period to make it sure that their surface was not exposed to any very destructive denudation at its close.

After about one hundred feet of coal-bearing beds had been laid down, there came a great change over all the physical and organic conditions—a change on many accounts the most inexplicable of any that are indicated in the whole series of rocks. We shall soon have to consider the nature and cause of this change; but it should be remarked, before alluding thereto, that this period, which we have called the Kentucky period, was, so far as our knowledge goes, peculiar to the Ohio Valley. In other regions the Millstone Grit, or the Conglomerate, comes immediately after the Carboniferous Limestone. In this region, the Carboniferous Limestone seems to have been brought to the water's edge sooner than at other points, and thus time was secured for the formation of the Kentucky shale. I am inclined to prefer this explanation to the hypothesis that the conglomerate-forming forces did not get into action at this point until long after they had begun to operate at other points, though this last hypothesis may turn out to be true. It seems to me probable that a set of causes, competent to bring about such an extreme revolution, would have acted over the whole region at the same time; or, at least, would have advanced with too much rapidity to leave time for the formation of these shales. It seems to me, therefore, that these beds are, in fact, Sub-carboniferous, answering to the later stages of the limestone period in other regions. There is, however, no sufficient evidence of this; and it seems to me, therefore, best to denote the doubt by a geographical name, which does not prejudge the question.

The passage from the Kentucky shales to the period of the Millstone Grit was apparently attended by a slight and exceedingly uniform subsidence throughout all the Carboniferous region known to us. This down-sinking was not accompanied by a return of the organic life which usually comes with the returning sea. A vast mass of sand and gravel, urged by strong currents, swept over this region; no marine life whatever was developed in it, and faint traces of land life have been found wherever it occurs. We find it by no means easy to explain this period, with its inundation of detrital materials, by anything in the existing conditions of the earth; but in the events of the glacial period, which has just passed away, something of similarity may be discerned. We may from that period construct a hypothesis which will in the main explain the conditions of the Millstone Grit time.

During a long series of ages, in which the Sub-carboniferous Limestone and the Kentucky shale were depositing, the surface of the neighboring land to the north and east was probably undergoing that process of slow decay which clearly goes on wherever the land is for a long time exposed to atmospheric action. In a few million years to come, provided the region is not ice or sea-swept, the great primordial region to the north will have its rocks decayed to a great depth, just as they are now decayed in the Unaka section of the Appalachian system, as has been described by Sir Charles Lyell, and later by Dr. T. Sterry Hunt. The granites, syenites, mica schists, and other allied rocks, might become so softened as to offer scarcely more resistance than incoherent sand to any abrading force. Now, when the great ice-sheet comes down again over this region with its rock-grinding forces, this decayed surface would be worn away with great rapidity, and the waste delivered to the sea, to be carried by it far and wide. We must not estimate the vigor of action of a moving glacial sheet by supposing it imposed on such a clean-stripped hard rock surface as we now find in the region north of the great lakes, but must consider it as generally acting on a region incoherent from decay for many feet below the surface.

The only material which holds its structure in the sort of slow decay which we have referred to, is the quartz, or other very silicious rock, which may be mingled with the more perishable materials; so that, in the movement of matter into the sea by the glacier, the quartz would be almost the only evaded material which would retain its form. That this hypothesis will reasonably well account for the most prominent features of the Carboniferous conglomerate series, will, I think, be evident to any one who will carefully examine its structure and contents. Wherever it occurs in Kentucky, it consists of thick beds of sand, composed of quartz and mica, with infrequent small bits of feldspar, the whole more or less mingled with pebbles of quartz and felsite, quite unmixed with any more composite rocks, such as granite or syenite. The thickness of this formation varies greatly in different sections in Western Kentucky; except in the pocket-like depression at Dismal Rock, the thickness does not exceed one hundred feet. The pebbles are small and not numerous, and the sand finer-grained than in the other districts. At many points the pebbles cannot be discovered, and the rocks are only recognized by their massive nature and the absence of all marks of life. In Northeastern Kentucky we have much the same features, though the pebbles are more general in their occurrence. As we go southward, along the Alleghenies, this formation increases in thickness, while the size of the pebbles remain about the same. Along with the increase in the thickness of the mass goes an apparent reduction in its Azoic character, there being more evidence of vegetation in Pennsylvania during this Conglomerate period. When we come to Cumberland Gap, the section containing pebbles exceeds three hundred feet in thickness, though it contains a small bed of coal in the very midst of the pebble-bearing rocks. This thin bed of coal occurs in the midst of some clays which are intercalated in the Conglomerate, and which seems to mark a temporary and local change in the conditions of its deposition. I am unable to offer any other explanation of the southward thickening of this formation in this field, except the fact that the high mountain region of North Carolina, which probably had several thousand feet more altitude than at the present time, is nearer to this section than it is to the northern part of Kentucky. In the distribution of the sediment of the Millstone Grit, this Unaka Island, as we may call the ancient North Carolina land, seems to have had more influence than the Laurentian Island, which lay to the north of the present position of the great lakes.

In Northern and Western Kentucky the Conglomerate period seems to have been followed by a period when the invasions of sand were rarer, and more mud, laid down in brackish water, was introduced into the Carboniferous section. In the Cumberland Gap section the sandstones predominate far more than in the other districts, showing plainly the greater nearness to the sources of those coarse sediments. In Northern and Western Kentucky there were several great invasions of the sea during the formation of the section which follows the Conglomerate. These returns of the sea appear to have brought tolerably deep water in more than one case. These intercarboniferous limestones demand, and will receive, especial attention from this Survey. At present, it is only intended to notice their occurrence.

The whole of the Kentucky section shows, in a distinct fashion, an extraordinary succession of upheavals and subsidences, bringing the region alternatingly above and below the water level. To understand this action, it is necessary to consider the following points:

We know that continents, as a whole, have probably a constant upward tendency, the periods in which their surfaces are borne down being temporary and more or less local. The theory of the formation of continents requires us to suppose that their constant tendency is upward. It is generally accepted that they are the result of the continued loss of heat from the earth, and the accommodation of the outer portion to the diminishing interior. This causes the superficial parts of the earth's surface to wrinkle, as the outer rind of an apple does in the shrinkage necessarily caused by drying. These earth-wrinkles, when once begun, tend constantly to increase in height. All through the history of North America the Laurentian Island and the Unaka Island, which seem to have been two of its principal nuclei, have been rising upwards, by the action of the subterranean forces, to meet the constant wear from the action of the solar forces operating through rain and ice. But in this normal uplifting action there come pauses or reversals of the movement, which demand more consideration than they have received. I have elsewhere endeavored to account for these changes in direction by showing that they may be in part produced by a mere change in the position of the fulcrum point of a see-saw movement in which, on the whole, the land is steadily going up and the sea floor steadily subsiding.* Another cause of subsidence is doubtless the existence of glacial envelopes at various stages of the earth's history. We already know enough of the history of the last ice time to be quite sure that, wherever the ice lay deep, there we had a lowering of the level of the land, which continued some time after the ice had passed away. It seems likely that there was a compensating elevation of the region south of the glacial line, occurring coincidently with the depression to the northward.

Without endeavoring to discuss the important and difficult questions connected with this field of geological inquiry, I will now call the reader's attention to the fact that the evidence goes to show us that the region of the Ohio Valley was a

* Memoirs Poston Society of Natural History, Volume II, p. 337.

vast and tolerably level district, the surface having been made horizontal by long-continued deposition of marine beds. This area of plains had come, at the Carboniferous period, to somewhere near the level of the sea. I am inclined to think, that at this time the northern hemisphere was under the influence of repeated and extensive glaciation. The evidence of this is found in the vast amount of detrital matter set in motion at this time, which apparently much exceeded in amount all that had ever been given to the sea since the organic record began. No period before or since, in the history of the earth, as far as known by us, has equaled the amount of mechanical sediment of this time. If I am correct in supposing that the Carboniferous period was a period of repeated glacial action, we may regard the luxuriant forests as occurring in the mild intervals of that glacial time. We have sufficient evidence that luxuriant forests, consequent on an excessive rain-fall, are possible associates of a glacial period. Without attributing too much importance to these hypotheses, I would sum up my conjectures concerning the conditions of the Carboniferous time as follows: that vast quantities of sand and gravel were thrown into the sea by glacial action. The successive uplifts and depressions, amounting to at least twenty near Cumberland Gap, were due to the changes in the ice-sheet or heavy coating of ice disturbing the equilibrium of the land. The rich vegetation may be accounted for, in part at least, by the abundant rains of that time.*

The Kentucky series of rocks closes with the middle of the Carboniferous period, and it is likely that the highest part of the Kentucky rocks does not extend above the middle of that part of the coal-bearing beds. The whole question of the relation of these beds to the Pennsylvania section is so much in

*It may be objected that the occurrence of coal within the arctic circle militates against this view. I have elsewhere tried to show that it is a natural consequence of a glacial period to so lower the land barriers about the pole that, by admitting the tropical streams, the arctic regions are kept at a relatively high temperature until the barrier of land rises once again. Without the machinery of the glacial conditions I am unable to get any clue to the repeated movements of the land, the great quantity of detritus, which, from its character, must have come from the neighboring granite areas, that are the natural seats of glacial action, or for the evidences of great rain-fall afforded by the carboniferous conditions.

doubt, and will require so much more evidence for its solution, that I do not venture to attach it here. Nor do I regard the contemporaneity of the beds at Cumberland Gap and in Northern Kentucky as sufficiently established. All the experience of the officers of the present Survey goes against the plan of endeavoring to determine the synchroniety of beds by their fossil contents, at least by their vegetable fossils. The geographical distribution of plants over a great section, even in very uniform forests of the Carboniferous period, makes this a dangerous method. In the hands of the great master of the subject, M. Lesquereaux, its results are not always satisfactory; and for the practical work of the field geologist it has relatively little value.

I very much doubt if a single one of the beds at Cumberland Gap can be traced through to Western Kentucky, and but few will find their determinable equivalents in Northern Kentucky. There seems an ideal reason why there should be some sort of identity between these beds at different points; but when we come to determine it in a practical manner, it is found quite difficult, if not actually impossible, to make sure of the identity.

The only beds above the carboniferous, which have been seen by this Survey, are the beds previously referred to in the region bordering the Mississippi. The general character of these beds is such as would be given by formation in fresh water lakes. The only consideration I shall advert to here is as to the method of inclosing a fresh water lake at this point. May it not be that, while the glacial period by its ice sheet caused the northern regions to sink down, the southern belt of land was coincidently uplifted? If this be the case, then it is quite possible that, during some of the Tertiary periods, this section was converted into a fresh water lake by the upheaval of the land to the southwards. I have long been obliged to conclude, from the phenomena of our coast line, that the belt south of the glacial line went up when that within the ice belt went down, and in turn sunk down when the ice-worn region, relieved of its weight, came again above the sea.

Having rapidly glanced at the remarkable succession of the phenomena of our Kentucky series, and endeavored to give some conjectures as to their meaning, I propose now, in closing, to note some points of a general character as to the origin of these sediments and their value as evidences of the geography of the times when the rocks they composed were laid down on the floor of the sea.

By reference to the several reports of the chemists of this Survey, it will be seen that there are a great number of beds in the State composed of materials containing a large proportion of soda and potash. Attention has already been called to the presence of considerable quantities of mica and quartz in the coarser sediments, such as the sandstones. These facts go to show that this region received a large share of sediment of the original granite centers of the continent, though these centers must have been more than five hundred miles distant on the northern and over one hundred miles on the eastern face of the State. That there were powerful transporting agents at work in this section is sufficiently shown by the great distances traversed by these waste materials.

All the coarse-grained rocks after the Cincinnati Group increase in volume as we approach the Unaka Island. In that group we find, as we approach the position of the Unaka Mountains, that the limestone becomes converted into a fine-grained shale of a red color, containing only small tribolites, just such an assemblage of characters as should be found in beds deposited in deep sea conditions in the formations answering to the Potsdam sandstone and Calciferous sand rock. So far as I have seen them, there is a remarkable absence of sandstones, which I cannot think could well have occurred had the Unaka Mountain Island been above the sea only forty miles away. I therefore venture to doubt whether this mass came above the sea until after the Cincinnati period. After that time every period except the Ohio shale shows the effects of its nearness to that mountain. The absence of any mark of mechanical detritus in the case of the Ohio shale leads me to think that that Unaka Island may have been again lowered below the sea, or in some way separated from the waters in which this shale was deposited.

CHAPTER III.

We come now to consider the events of that great succession of periods of which no distinct record has been left to us, owing to the fact that the State was above the level of the recording sea. On the west of the Mississippi we have evidence of several fresh water deposits, which hold large quantities of remains of animals of early Tertiary age. Along the banks of our rivers many such deposits must have been formed in each of the successive ages; but while the region of the *Mauvaises terres* and other western Tertiary localities have been exposed to a comparatively light rain-fall, and consequent slight erosion, this Ohio Valley has probably always been the seat of very active erosive forces ever since the formation of the Appalachian chain, owing to the large rain-fall that must have been always brought by the counter trade-winds. In the olden time, when the Appalachians had probably double their present height at least, the rain-fall would have been much greater than it is at present. Owing to this great and incessant wear, the records made in fresh water lakes and beds bordering the rivers have been all swept away within a short time after their formation. There are but two or three points in the State where there seems to be a chance of finding Tertiary deposits of any considerable age. These are in the detached bluffs along the Mississippi river, which have not as yet begun to be examined. It will be only a fortunate accident that can give us their animal remains of any considerable antiquity, so great and incessant has been the erosive action of the Mississippi. The only hope we can have of getting more records of the land life of the remote past of the Ohio Valley is in the deposits made in the caverns which are so plentifully interspersed throughout the State.

In the first volume of the Memoirs of this Survey, I have endeavored to give some facts and opinions concerning the antiquity of the caverns and cavern life of Kentucky. There seems no good reason to hope from them any records that will carry us back further than the early part of the Miocene period, if so far. The rate of erosion in this country at the present time is carrying the surface downwards at a rate which cannot be reckoned at less than one foot in seven thousand years, and probably much more rapidly; so that the uppermost of these caverns known to me in this region cannot well have an antiquity exceeding two million of years, which does not probably take us back of the Miocene period. No extensive excavations have as yet been undertaken in this cavern district. In order to make this search profitable, a thorough preliminary reconnoissance should be made, with a view to ascertaining where there is the greatest likelihood of success. It is manifest that the best chances will be found in the uppermost set of caverns, or, better still, existing in the crevices which are sometimes found in the summits of hills where the old caverns have lost their roofs, and only the accumulations formed in their halls remain to attest their former existence. It will be only after the most detailed study of the State, that there will be a sufficiently accurate knowledge gained to search these records with intelligence. When we consider, however, that the whole surface of the limestone districts is scattered over with sink-holes, that, to the number of hundreds of thousands, afford a sort of trap for the capture of the remains of land animals, which are swept down into the caves beneath; when we, furthermore, consider that, by the action of mud-accumulation and stalagmitic growth, the upper level of caverns is always tending to closure, it will be readily seen that a vast amount of the remains of the land animals which have lived in this district must be entombed in its caverns.

We get some idea of the later stages of the land life of Kentucky from the beds which have been formed by the salt springs or lick deposits of the State. Big Bone Lick, the most extensive of these accumulations, has a world-wide celebrity on account of the occurrence there of remains of gigantic mammals of extinct species. The great importance of the record it has preserved for us makes it desirable to give some better account of this, as well as other deposits of a similar nature, which I shall now proceed to do.

The fact that, during the period of the calciferous sand rock, there was a considerable deposit of salt in the region about Cincinnati, has already been remarked in a preceding chapter of this report. This store of saline matter remained intact during all the time when the superincumbent beds were wearing away from this surface. Now, that the level has worn down near to the calciferous sand rock, the surface water penetrates into this formation, and works up again to the surface at various points, always in the bottoms of the valleys, making saline springs. Owing to the circumstance of their discharge in the lowest level of the valleys, these springs frequently form a boggy place around their mouths. At times these bogs are extensive and the mud many fathoms deep. Big Bone Lick, in Boone county, is the largest and most famous of these licks. There the saline waters come up at various points over an area of about sixty acres, as rather large springs, each of which, unless artificially confined, oozes out through a large boggy area which may be fifty feet across. These springs have been liable to changes of position—much of the area that is now hard ground bearing evidence of having been at one time in the soft state which is now peculiar to the points immediately about the springs. The valley of the creek in which these springs lie is widened at the point where they occur to an unusual width. The neighboring table lands have a height of about two hundred and seventy-five feet. At some points near the base of the escarpments of the table land there are indications of disturbance in the limestone rocks, which can only be accounted for on the supposition that these springs have gradually carried away in a dissolved form a great mass of matter from the underlying rocks, thus bringing about subsidences in the section. I am inclined to think that the annual waste from these springs amounts to something like four thousand cubic feet of solid matter per annum. When we come to reckon this back for only a few hundred thousand years, we are forced to the conclusion that these springs must have taken out a great deal of matter from a large extent of territory.

These springs, when first visited by the white man, presented a surprising spectacle. All around the springs the ground was trampled bare by the myriads of buffalo that resorted to their waters for salt. In those trodden grounds lay quantities of bones of gigantic size belonging to the extinct elephants of this region. The fact that these bones lay loose upon the surface is to be explained by the incessant trampling of the buffalo and by the stream, which, at its flood, sweeps over this lowland, excavating the low banks in which these bones lay buried. The successive collections made at this point, during the last part of the last century and the early part of this, have been so large that we must reckon the amount of bones originally exposed at tens of tons in weight. There doubtless still remain the fragments of many thousands of individuals entombed in these swamps. These remains are generally comminuted by the treading of the living animals, often worn to mere pebbles of bone. I do not believe that any perfect animals are likely to be found in the swamps near the springs. At the very top occur the last that died, the bones of which were not trodden by any gigantic animals. Lower down we have only remains which have been ground as in a mill by the feet of their struggling kindred.

It is only at points remote from the springs, where the beds seem to have been formed by a mixture of the creek mud and the waste from the springs, that we find the remains in the order which will enable us to form some opinion as to the succession of occurrence of these animals at this point.*

After a good deal of necessary exploration I succeeded, in 1868, in finding one place where there seemed to be a dis-

*See Appendix to the Memoir of Mr. Allen, in the 1st volume of the Memoirs of this Survey.

tinct order of succession. At this point, at eight feet from the surface, I found *Elephas*, supposed to be *E. primigenius?* and *Ovibos* (*Boötherium*) *cavifrons*, and finally *Mastodon ohioticus;* above the *Mastodon ohioticus*, a horse, seemingly perfectly comparable in age with the mastodon, as far as all indications derived from its condition, and indistinguishable in its teeth from our domestic horse; the caribou, and possibly elk—the former proven by its horns alone—also the bones of the *Bison latifrons;* above these the common buffalo, the bones of which are not found at any great depth, except in the bog about the springs. While retaining a good deal of doubt as to the certainty of this evidence, I am inclined to think it likely that the mammoth (*Elephas primigenius?*) came before the mastodon, and was extinct or nearly extinct some time before the latter beast had begun to fail. With the mammoth we had the large *Ovibos*, called *Boötherium* by Leidy. I find no trace of its remains near the surface. The only point I deem well proven is, that the musk ox and the caribou did not come into contact with the recent buffalo, but were extinct before it came here. It is also pretty certain that the *Elephas primigenius* and the *Mastodon ohioticus* were both anterior in date to the buffalo, and it is sufficiently proven, on other grounds, that the mixture of their bones here is clearly due to the degradation of the original deposits and the consequent displacement of the bones of the elephants.*

It is in the highest degree desirable in the interests of science that these licks should be worked to their very bottoms in search of their possible contents. While I cannot hope that we shall recover any remains of a date older than the early Pliocene, we may at least hope for a great addition to our knowledge of the Kentucky fauna during, and possibly just anterior to, the glacial period.

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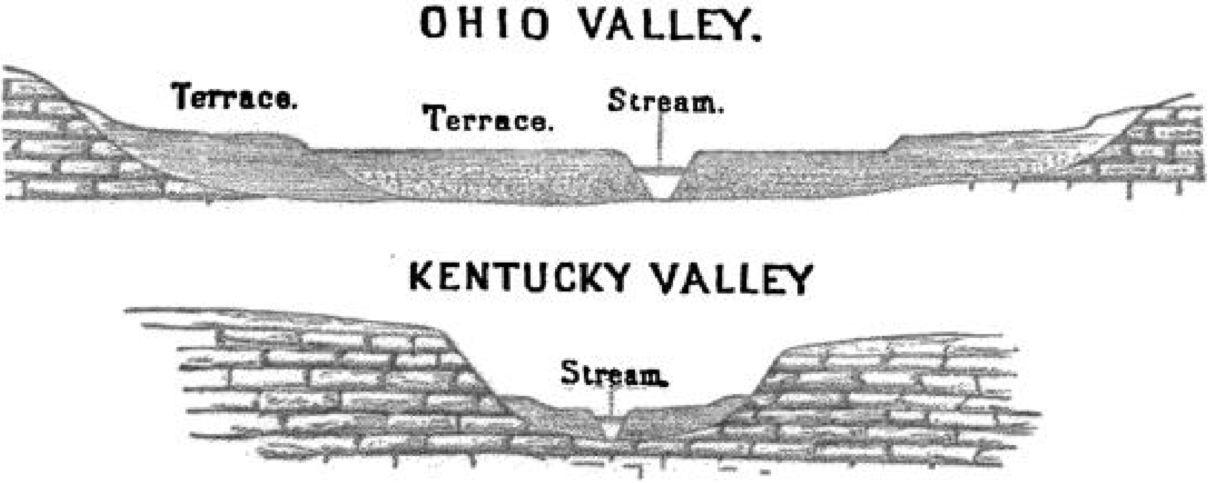
* The excavations were made by me at my private expense, and in part by means furnished by Mr. James M. Barnard, of Boston, who, with the ready devotion to the cause of science and all other forms of human culture, for which he is so well known, shared the cost of the collections then obtained, amounting to at least a ton of bones. These collections are now at the Museum of Comparative Zoölogy, at Harvard University, and have furnished the basis of the admirable memoir on the distribution and history of the buffalo, by Mr. Joel A. Allen, which has just been printed in the Memoirs of the Kentucky Survey.

I have done much work with the hope of determining the relation of age between these deposits and the drift period. There is, however, scarcely anything that can be called certain evidence on this point. The drift beds do not reach south of the Ohio in this part of the valley. By a judgment, based on the appearance of the wear which has taken place since the glacial period and since the deposition of these remains, I have come to the conclusion that they are of about the same age. The evidence derived from other sources is sufficient to prove that both these elephants survived the closure of the main glacial action for a very long time; so it is likely that they overlapped that time in this district as well, and may have continued down to a relatively recent time. It is probably in this belt of country, just south of the southernmost line of glacial action, that the mass of creatures driven south by the ice-sheet remained, until that great invasion began to retreat to the northward.

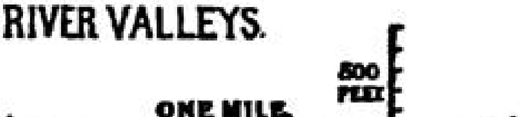
In this connection we may notice the river valleys of Kentucky, which have much to interest the student of these remote times. As regards their valley phenomena, we observe, that, while the rivers which discharge into the Ohio from the northward are characterized by having broad troughs, in which the rivers meander across a breadth of alluvial or interval land, those which fall into it from the south have only narrow gorge-like valleys, not averaging one half the width of their northern representatives. This I believe due to the fact that the northern tributaries of the Ohio flow in valleys which were swept by the southern branches of the great continental glacier, while those in Kentucky have, ever since the formation of their present beds, been flowing in channels worn by running water alone. These differences are the characteristic differences of valleys cut by ice and by water. The effect is to give to the northern streams a wide belt of interval land which is gradually built up by the successive floods, and is cut away by other floods only to be built again.

We have north of the Ohio no such extended cañons as are found along our rivers, especially along the Kentucky and the Green, where for great distances there is hardly a fringe of alluvium to border the stream. Moreover, the southern tributaries of the Ohio flow through much more tortuous valleys; they make, on the average, nearly twice the distance in going a given number of miles of direct course. When valleys have been shaped by ice they run in much more direct lines than when the only shaping agent was running water. This matter is, however, foreign to our present inquiry, which concerns the problems connected with the formation of the river deposits within the State. These deposits along the Ohio are so curious and so varied that they deserve the consideration of a special memoir, which I hope some time to give to their study. I wish here to touch upon some points which may be elaborated hereafter.

The Ohio Valley has the character of width which belongs to its tributaries from the north, though in a relatively less degree. The great Miami, for instance, has a valley about as wide as that of the upper Ohio; and the same may be said of the Sciota and Muskingum; but there is, on the average, nearly two miles of distance between the hills in the section from Louisville to the Chatterawha or Big Sandy river. The section across this bottom varies a good deal generally. It may be typically represented by the following diagram:

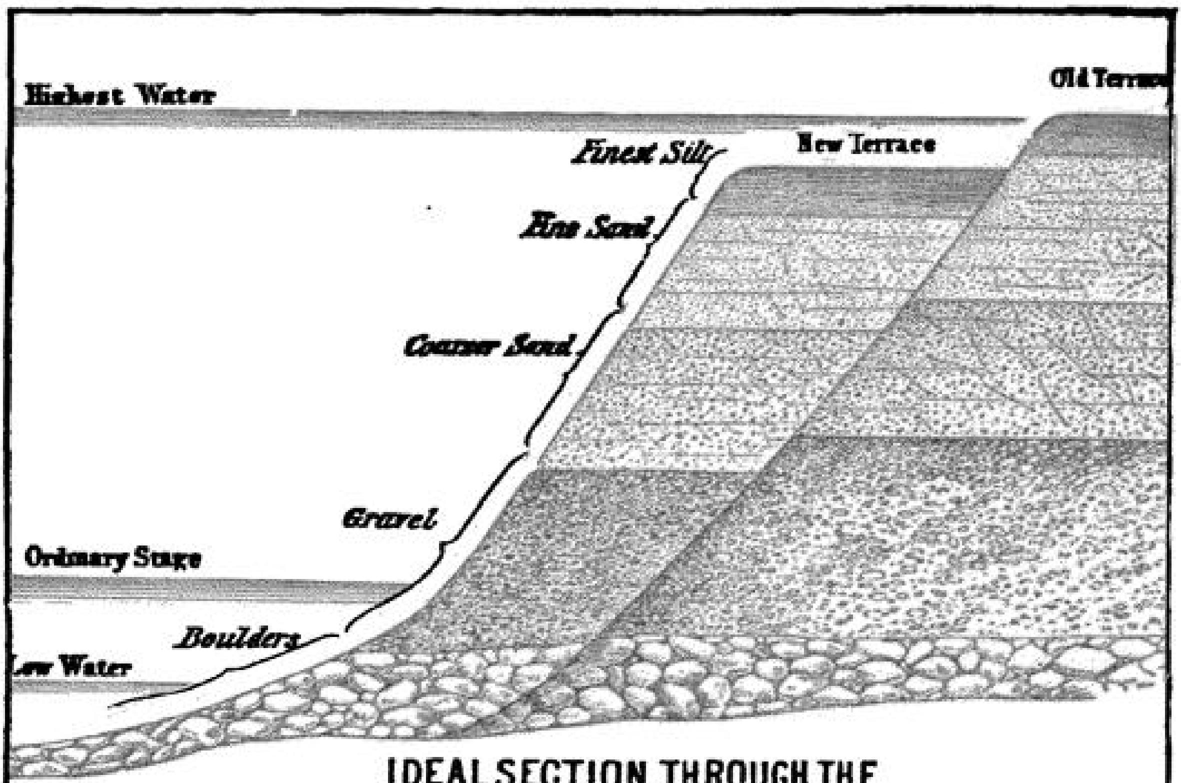


DIAGRAMATIC SECTIONS ACROSS THE
OHIO AND KENTUCKY RIVER VALLEYS.



In this we perceive that the table land on either side of the river slopes in an extremely gradual manner towards the main stream. The bluffs, constituting what are erroneously called the river hills, descend abruptly to the plain. The basin consists of two elements, the rock bed and the detrital materials. This rock bed has been plowed out by the stream, working now here now there, in its migrations to and fro over the valley. It generally slopes towards the present bed, because the stream has worked there last. The waste matter or alluvium of the valley tells more of the history of the stream than does the rock basin. The general distribution of this matter is in a succession of terraces, one above the other, and with areas usually proportional to their height above the stream; also the height of these terraces above each other is less and less as we ascend the river. The first terrace lies always at just the high water mark of the floods of the region, for the good reason that the degradation from the action of atmospheric forces is just balanced by the mud laid down by the stream. The other terraces mark the newer deposits. The older they are the higher about the present bed. On these terraces denuding agents have been effectually at work, and they are generally the more exposed the higher they are; so the upper terraces are not often distinctly defined one from the other. These terraces, conspicuous at all points, are most extensively shown near places where the tributaries from the north enter the Ohio. At such points there is generally an erosion circus of considerable area. It seems as if the river has been driven about by the accumulations of materials brought down by the tributaries in such fashion that it is compelled to widen its bed. The conditions at Cincinnati strikingly illustrate this action. In a remote past, it is evident that the stream at this point was driven about so as to excavate an extensive circus, which has an average diameter of about three miles. The remoteness of the time when this action took place may be determined by the height of the terraces above high water mark. Some of them rise to at least fifty feet above that line; yet these upper terraces, being covered by drift of granitic pebbles, must have been deposited during, or just after, some period of glaciation. I am far from certain that this was the last glacial period. I shall, indeed, endeavor hereafter to show special reasons for doubt on this point. It seems very probable, as has already been pointed out by several students, that the great Miami at one time entered the Ohio at the Cincinnati circus; in which case we may regard the part of this area which is on the north of the Ohio, as formed by the Miami, rather than by the Licking and the Ohio. It may be given, as a general rule, that wherever a tributary enters the main stream, there is just such a terraced plain as lies on either side of the Licking at its mouth; and is also found at the mouth of the Kentucky, the Scioto, and more or less distinctly at the mouth of all the other tributaries of the Ohio. I am inclined to think, from my observation of other streams, and such good maps as I can obtain, that it is not peculiar to this stream, but belongs of necessity to every river system. These excavation areas are probably due to the interaction of the currents of the two streams in several ways. In the first place, the tributary has generally a far more rapid current than the main stream, and consequently deposits a large share of its heavier detritus at its mouth. This tends, in the first place, to shove the main river against the bank opposite from the entrance of the stream. Something of this action is observable at several points along the Ohio river; but the more prominent result is to build bars across the mouth of the tributary stream, causing its currents to be forced now in one direction, now in another, and so wearing out a wide basin at its mouth. It is in these intersections of the main stream and the tributaries that we find the oldest terraces that exist along the main river; those at Cincinnati being, to the best of my knowledge, the highest that occur at any point within the valley.

We now come to consider the structure of these terraces, and though this varies a good deal, it is essentially uniform.



IDEAL SECTION THROUGH THE TERRACES OF THE OHIO VALLEY.

The diagram given above will serve pretty well to show the general plan as it is seen wherever a section can be obtained. At the base we find a layer of water-worn pebbles, often of great size, it being not infrequent in the older drifts to obtain pebbles near a foot in diameter, and always profoundly water-worn. In the newer deposits of the Ohio river, the pebbles are probably not anything like so large as in the older deposits, a point into which we will need to examine hereafter. Above these pebbles, and mingled with them, lies sand of different degrees of coarseness and smaller pebbles, the whole being stratified by the action of the water in the way we so usually find in such deposits, the beds generally dipping to wards the river, though often irregular in this regard. Above these, and in the case of the lowest terrace, at points, say twenty-five feet above low water, we come at length on the fine loam, which becomes generally less and less sandy as we approach the top of the terrace. Near the top we have generally a sheet of half decayed humus, at various points near the surface, showing the line of ancient soils.

It is a noticeable fact, and one often remarked, that the part of the newest terrace—that still growing, is highest near the river, and slopes back to some drainage, which is generally in the shape of a creek flowing against the escarpment of the rocks in which the stream is excavated. The process of this growth seems to have been generally as follows: whenever the river is diverted from its course, and thereby begins to work with less force against one of its banks and with greater force against the other, the slackening current first leaves there the pebbles of the large size that the stream ordinarily carries; then, as with the extending diversion of the stream the current still further slackens, the materials of less weight will fail to be carried on. As the new terrace gets still higher above the bed of the stream, a finer class of detritus will be laid down on it, until the fine sediment borne near the top of the stream will be the only material lifted to its level. The result is, that, no matter how many times the bank is washed away and filled in again, it will have the same general character.

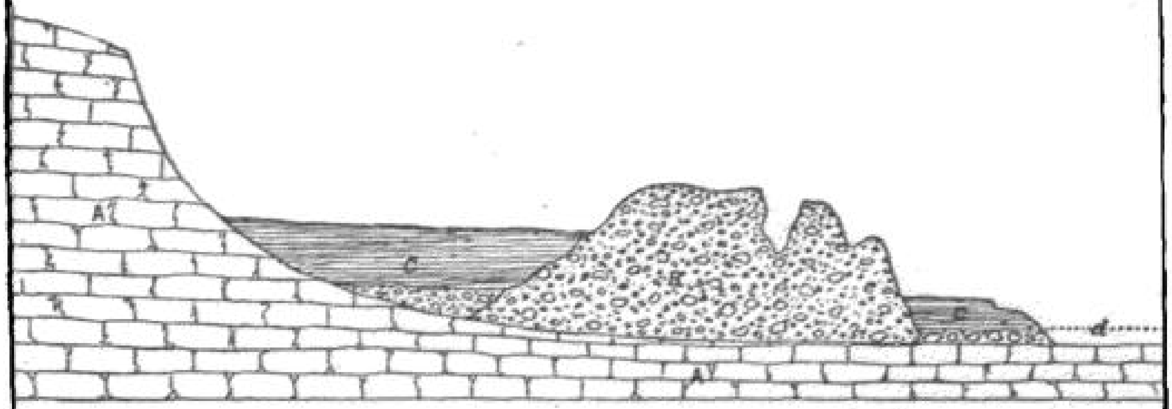
It is necessary to call attention to certain peculiarities of these terraces, which tell an important story. The second bank at Newport, and at various other points—the bank which has its top about twenty-five feet above high water, contains a good deal of a tough blue clay—a clay wherein the mud is finely triturated, and which owes to some peculiarity a grey-blue tint, which is by no means common in our clays. I have never found this clay away from regions affected by glacial actions. I am inclined to think that it was formed at the time the valley was swept by the floods, which came during and at the close of the glacial period, when, for a great length of time, this valley was the seat of a far more powerful stream than at present. There can be little doubt that the glacial period was a period of greater rain-fall than the present time. In no other way can we account for the making of such a vast ice-sheet and the supply of the great amount of water necessary for its continued movement. There are many facts which go to show that the action of cold alone could not, by any means, account for the formation of an ice-sheet extending down to Southern Ohio.

The whole of British America east of the Rocky Mountains has the temperature necessary for glaciation, as has all Siberia, but the deficiency of water makes it impossible for such ice-sheets to form; showing clearly that a considerable rain-fall is necessary to the maintenance of glacial conditions. Moreover, as I have elsewhere remarked, the assemblage of animals living in this country, during or just at the close of the glacial period, makes it quite certain that the conditions favored a luxuriant vegetation, and gave this region a climate in which extreme winter cold could not have existed. These species were all large representatives of their several groups, their great size making it clear that they could not have struggled with difficult conditions. Accepting the glacial period as a time of heavy rain-fall, we can readily account for the width of the Ohio Valley, and for the indications of energetic excavation seen there and in the valleys of its northern tributaries. The entire absence of unstratified drift in the Ohio Valley, and the absence of glacial pebbles on the Kentucky table land, has led me to the conclusion that the ice-sheet never occupied the valley of the Ohio. Some little search on the north side of the river has led me to the conclusion that the southernmost point of the glacier was at some twenty miles north of Cincinnati. I have seen some half a dozen boulders of hypogene rocks lying on the table land south of the Ohio in Boone, Kenton, and Campbell counties; but these were all under six inches in diameter, and rather symmetrical forms; so I have been driven to the conclusion that they were brought to their present position by the aborigines. There are a few facts, however, which require notice in the surface deposits of these counties; facts which, I confess, I cannot readily explain, though I do not believe they are connected with the actions of the last glacial period. In Kenton county, just back of Covington, at a height of three hundred feet above the river, there are a few patches of a deposit which has a thickness of twenty feet or more, and seems to be the completely decayed residuum of some deposit which contained small pebbles of granitic rocks. I propose to make a careful study of these beds, but I believe that they may be regarded as the remains of ancient deposits, formed when the river bed was some two hundred and fifty feet above its present level. Should it ultimately be proven that this is the true explanation of the phenomena, it will possibly show that, long anterior to the last glacial period, some agents were at work, which were competent to bring the waste from the north of the great lakes down to the Ohio River Valley. This agent could not well be other than ice action; and if the facts are read aright, we have in them yet other proofs of ancient glacial action.

Another puzzling set of facts of the same general character is found in the valley of the Licking, at a point called Flatwoods, about sixteen miles south of Newport. There, at a height of one hundred feet or more above the present high water mark of the Licking river, we have in a broad valley quantities of fragments of cannel coal, mixed with bits of sandstone and limestone, the whole forming a coarse breccia. I gathered dozens of these fragments of coal in the course of half an hour's search. I cannot believe that they were brought here by aborigines, for there are no other signs of their presence. I cannot believe that they are the remains of a bed deposited on the spot, but I regard them as material brought here by the Licking river during the time when it ran at a higher level, and when the coal beds were probably far nearer to this place than they are at present.*

Yet another case of the same general character as the preceding is found on the Kentucky side of the Ohio river, at a point opposite and a little below Aurora. The accompanying section gives the most essential relations of this singular mass:

* I am indebted to my friend, General G. B. Hodge, of Newport, Kentucky, for calling my attention to these very interesting facts.



DIAGRAMATIC SECTION of the ANCIENT RIVER CONGLOMERATE
and the newer river beds on the Ohio River near Aurora.

A. A. Bed and Cliff Rocks.
B. Ancient Conglomerate cemented with lime.
C. C. Recent alluvial deposits.
d. Level of river at low water mark.

This deposit is a Conglomerate belonging to a time more ancient than the last glacial period, but more recent than the formation of the valley. The mass contains far fewer granitic pebbles than usually belong in the river pebbles. It is clearly stratified, and the thickness cannot be less than one hundred feet. The cement is mostly carbonate of lime, and was doubtlessly derived from springs coming from the neighboring hill; but the geography of the country must have changed a good deal since this action took place. The valley has widened so as to make the invasion of such waters quite impossible. This deposit seems quite without contemporaneous organic remains. It cannot, however, have a very great age, for the valley had been cut down to within one hundred feet of the present level before the deposition of these beds. At no other point in the Ohio Valley have I seen anything like these masses of pebbles.

The cutting rate of the Ohio since the glacial period is approximately determined by the height of the highest terrace containing pebbles carried, from north of the St. Lawrence, and of sufficiently recent aspect to be classed as belonging to the last glacial period. I am inclined to think that the down-cutting has been not far from seventy feet since the highest of these deposits was formed. I am satisfied that it is at least fifty feet. This may represent the time back to the beginning of the glacial period, or at least to its early stages. As there is little reason to doubt that the average erosion rate in the Ohio Valley is as much as one foot in three thousand five hundred years, we can reasonably suppose the post-glacial erosion of this new bed may be as much as one foot in, say two thousand years, or about twice as fast as the average erosion of the whole country. This would give something like one hundred thousand years as the time which has elapsed since the stage of the glacial period, when these upper terraces were deposited.

The upper terraces of the drift contain very often the bones and teeth of *Elephas primigenius*, the latter in a good state of preservation. From a terrace in the city of Newport, about twenty-five feet above high water mark, at a depth of forty feet, a molar tooth of this species was exhumed which was but little worn by water action; so there can be no doubt that this terrace was formed during the mammoth period. I have never heard of this class of remains in the last or lowest terrace of the river; on the other hand, I have found in this terrace, buried in some cases several feet below the surface, remains of the people of supposed mound-builder age. About twelve miles above Newport, on the Campbell county shore, there is evidence of an extensive camping-ground, where pottery was made and broken in great quantities. This deposit is buried under some five feet of alluvium. The remains scattered about through this deposit include all our ordinary game animals, which would be eaten by the Indian, except the buffalo—no trace of which have I ever found among the remains of the people of the earliest human age in this State. The position of these remains from the above cited locality indicates no great antiquity. The bank near the river may be worn away and restored several times within a thousand years. The evidence of antiquity increases as we get away from the present shore; so that remains found buried in the terraces at, say half a mile from the bank, would reasonably be inferred to be older than when they had come from quite near the shore. The only evidence of value, however, is to be found in the height of the terrace above the high water level.

As before remarked, the terraces of the tributary rivers arising in Kentucky are much less conspicuous than on the main Ohio. Although not yet fully examined, these terraces, owing perhaps to the narrowness of the valleys of the streams, are fewer in number and less distinct than along the main stream or its northern tributaries.

I have not been able to find in this Commonwealth any trace of ancient gravels which have come from north of the Ohio—the whole evidence going to show that there has been, within the time that a granitic bowlder can endure near the surface, no glacial action that could bring the northern drift any distance south of the Ohio. The only foreign pebbles which can be referred to these deposits are the pebbles of white quartz. The obstinate endurance of this material enables it to exist long after all granitic and similar pebbles have been swept away by decay. This will make the pebbles of quartz the last surviving remains of the last glacial drift. There are such quantities of these pebbles scattered over the State, that I have been disposed to regard their frequent occurrence as proof that we had the waste of old glacial periods surviving on its surface. I am, however, doubtful whether they are not derived from the several conglomerates which once existed in the recently eroded rocks, especially in the carboniferous Conglomerate, or Millstone Grit.

I propose now to give some general consideration to the soils of Kentucky, with a view to setting forth their most important phenomena, as far as observed, and of indicating the problems which should occupy the attention of the Survey. Although the existence of all civilization, the very power of the earth to sustain its present population, depends far more upon the character of its soils than upon its bed rocks, they have received relatively little attention from the students of nature.

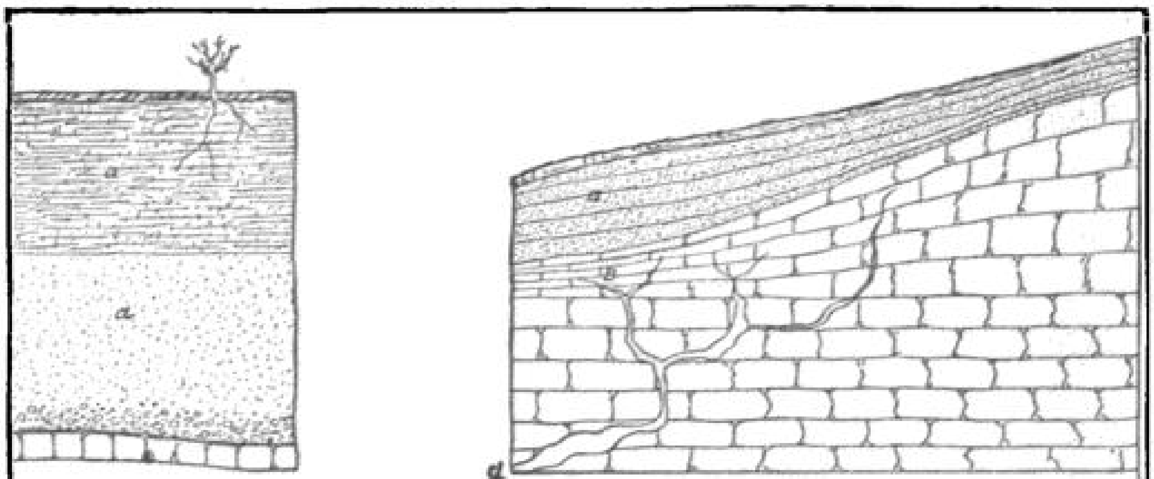
As is well known, a soil, whatever be its character and origin, is composed in the main of the waste of the rocks which constitute the surface of the earth. Its possible fertility, if not its actual fruitfulness, depends almost altogether upon the chemical and mechanical composition of these materials. The vegetable and other organic matter may be readily lost or gained; but the components, which come from the rocks, give the essential character to the soil.

For the purposes of description, soils may be divided into two classes, viz: those of immediate and those of remote derivation. The first of these groups, the soils of immediate derivation, includes all those soils whieh owe their components to the decay of the rocks which immediately underlie them. The second of these groups includes all those soils which have been composed of materials brought from a distance, and do not at all depend on the underlying rock for their character.

Soils of immediate derivation may be regarded as parts of the rocks of the district, modified by eroding agents. In those regions where they occur, the geological structure is indicated by the structure of the soils—these superficial beds furnishing the best possible clue to the geology of the country. In the regions where the rocks are of remote derivation, they always indicate rather the structure of some other region than that of the country where they are found. All the region covered by glacial deposits, whether retaining their original composition or rearranged, and the valley borders of streams formed by alluvial deposits, may be regarded as soils of remote derivation. Save under the glacial belt, the soils away from the river banks are normally of immediate derivation. Such they are in Kentucky, except along the banks of the streams.

Considering first the river soils, we have to notice that the soil of any valley is a sort of average of the materials which belong along its shores, above the point where the specimen is taken. Along the Ohio, for instance, where at every point we find a soil derived from a very great variety of formations, there is little difference in the character of the alluvial lands, throughout its course, within the State of Kentucky. This is not the case on the smaller streams. The valley lands of the Licking, for example, are rather poor as long as its waters lie within the rocks above the Silurian, and very steadily increase in fertility as we penetrate further and further into the Paleozoic section.

The alluvial lands of the lower part of the Kentucky river are much richer than the Licking. It is not necessary to follow this into details with the other streams; but I wish to indicate the general principle that the average fertility of any valley may be determined by the character of the rocks whence the alluvium is derived. The peculiarity of these river soils is their depth at every point. They have about the same inorganic contents. Every part of them is capable of sustaining life. The relation of soil and subsoil does not exist here with the same clearness that it does in the soils of immediate derivation. The comparative sections are generally more or less as given in the accompanying figure:



RIVER SOIL

a. a. Soil brought from above by the Stream.

UPLAND SOILS

a. Soil composed of Rock decayed in place.
B. Partly decayed Rock.
d. Cavern with its Branches.

When the soils of the Silurian limestone are studied, it is then seen that the mechanical conditions, as well as the chemical constituents of the soils, vary exceedingly at different points in the section. Generally the virgin soil is divisible into several sections. The topmost is characterized by a loose texture, caused by the long-continued penetration of roots, which, by their decay, give the soils an open texture, and facilitate the passage of water. From this point downwards the insensible change carries us through more and more dense matter, until we come to material which retains the stratification of the limestone, being, in fact, the original bedding out of which the lime has been entirely washed and the other matters, left from the leaching, packed into narrower compass by the pressure of the overlying beds. I believe the shrinkage from this leaching amounts, in many cases, to more than eighty per cent., so that six inches of argillaceous sandstone may represent a bed originally more than one foot in thickness.

Penetrating through these arenaceous foundations of the soils, the streams, whenever there is a limestone base, gather themselves into subterranean courses, which are dug out by the chemical and mechanical actions that gives us our caverns.

The enormous area of these caverns, their evident continuous growth from an antiquity of hundreds of thousands of years, the great thickness of these slowly-leached soils, all together give us proof of the antiquity of something like the present conditions in Kentucky. If the forests, or, at least, the vegetation, had ever been interrupted, it would have necessarily led to the stoppage of the leaching of our limestones and the arrest of the growth of our caverns; for the eroding agent, both in soil and cave, is the carbonic acid derived from the decaying vegetation and absorbed by the water.

The under-drainage of a soil is evidently the first condition of its great fertility. Soils of immediate derivation are only thick where this underground system of waters is well developed; but it is evident that this process of gradual decay must be exceedingly slow.

CHAPTER IV.

DYNAMIC GEOLOGY OF KENTUCKY.

Hitherto we have considered the rocks which are visible within the Commonwealth, and the forces engaged in the transportation of the materials which compose them. We are now to turn our attention to an entirely different class of facts and inferences, viz: to the nature of the forces involved in producing the dislocations, the faults, folds, and earthquake movements, or the general tilting of the rocks which may have occurred within the State.

All of these actions are dependent on conditions which are brought about far below the limit of our observations. All we can ever know of the forces which bring about the earthquake or the mountain ridge, is through inferences made from our study in the laboratory, or from the examination of rocks which once laid far beneath the surface, but which have come to the surface through the action of elevation and erosion.

The various forces, which, originating in the unknown depths of the earth, are propagated to its surface, may be divided into two classes, as follows:

1. Forces which are connected with the translation of heated matters, from the interior to the surface, such as volcanoes and solfataras (or cold gas volcanoes).

2. Forces which manifest themselves only by dislocations of the superficial rocks—dislocations which may be only temporary, as in the surgings of the earthquake, or permanent, as in the foldings of a mountain chain.

This classification is, as I am well aware, only a convenient method of assembling phenomena, with which we have necessarily but little acquaintance; but it will serve to distinguish two sets of accidents which have different fields of action, and probably somewhat different causes of origin.

The first of these causes is unknown in Kentucky. The general law that volcanoes are universally limited to the sea shores, never occurring more than two or three hundred miles therefrom, secures us from any risks of such accidents in this area. Not only is this region without any trace of modern volcanic action, but there is every reason to believe that at no time within the vast period recorded in its great stone books has it ever contained any of those volcanic events which are so prominent a feature at many points on the earth's surface, and which at one time or another have been developed over almost all of its land areas. Many countries, which now are quite free from such accidents, were at other times completely riddled by volcanic chimneys. Great Britain, Germany, and France, which have never seen a trace of eruption in the historic period,* have all over their surface the scars of ancient volcanoes. But Kentucky and the neighboring districts of the Ohio Valley give us a region—the largest known in the world—characterized especially by the entire absence of all marks of igneous action. I do not know of a single mark of volcanic activity in the area of two hundred thousand square miles, with Cincinnati as a center. I very much doubt if there is a single dyke of igneous rock within two hundred miles of radius from that city.

But the subterranean effects of the heat of the earth, the squeezing and folding forces which lift up rocks into mountains, and in so lifting break great sections asunder, have left abundant marks upon the surface of the State. Those marks do not by any means indicate all the discharges of internal force which have come to the surface; for, as we shall see, the wonderful earthquakes of 1811–13, despite the fact that they shook the State to its furtherest borders, and made the whole continent tremble, left scarce a trace on the surface that is visible to the present day.

As our studies will be limited to the dislocative forces, I propose to divide our considerations into those which concern dislocations proper, faults, and folds, and afterwards to take up the phenomena of earthquakes, so far as they are illustrated by the shocks which have taken place within our border.

* Saving *possibly* Central France.

The dislocation phenomena of Kentucky are a part of a system of disturbances which cannot be understood by tne study of the area found within the State alone. They have been brought about by the building of the whole continent; and, to be properly studied, must be taken up as problems in the general architecture of North America. It is out of the question to give any such general study to these questions within the limits of this report. Moreover, the structure of the mountain system of the Appalachians is a problem which is not likely to be solved for a century to come. The most that can be done by the Kentucky Survey is to determine its features within the limits of this State, and to show how they bear on the general question of its origin and structure.

The studies which I hope to see made on this system, as developed within the State of Kentucky, have been but begun, and it will require years to bring them to anything like completion. There are, however, a few points which seem to me sufficiently well observed to warrant me in giving them a place in this report.

I shall first consider the Cincinnati axis, as that is most distinctly a Kentucky problem. This axis is essentially a very broad mountain fold, beginning on the north near Lake Erie, and extending southwardly across the whole of Kentucky and Tennessee to Alabama, having a total extension of near six hundred miles. Its general course is not far from north 20° east to south 20° west; but owing to its great width, and the consequent indistinctness, it is not easy to assign it a definite compass course. The width, as compared to the height of this ridge, is singularly great, and makes it, as far as my knowledge goes, quite unexampled among such elevations as far as they have been described; for while the greatest height, measured from the depression on the eastern side, does not exceed fifteen hundred feet, the width is not far from one hundred and fifty miles. This height is, of course, not the geographical, but the geological height: *i. e.*, the extent to which the beds of rock have been thrown out of their horizontal position. It is difficult to determine the exact height or width of this ridge on account of the indefinite character of its curves. I have preferred to take the deepest part of the synclinal lying between this ridge and the Pine Mountain, or the other westernmost outliers of the Alleghenies, as the basis from which to measure. This depression, which I shall call the Ohio synclinal, gives a better basis for measurement than the western slope of the anticlinal, which falls away in an extremely gradual manner into the Mississippi basin. The Ohio synclinal is, as are most synclinals, in no sense a valley.

The height of this anticlinal varies materially at different points, as in many other mountain ridges which are closer to the normal type of mountains. This Ohio anticlinal is higher near its extremities than in the middle section. At Lexington this height is as much as fifteen hundred feet. At Nashville it must be about as much; but, at a midway point between these places, the top of the anticlinal has sunk to less than nine hundred feet. The general character of this anticlinal is that of an extremely gradual and uniform curve, with very little accompanying dislocation. The curve at some points seems to be complicated by small variations of height; but I am inclined to believe that these undulations are mere local accidents, and not in any way dependent on the forces which made this broad anticlinal.

Along the Kentucky river, where we have the most elevated part of the ridge within the limits of the State, if not in its whole length, we have a set of dislocations, in the shape of faults, which pretty nearly follow the general trend of the Kentucky river, and have probably been in a measure the determining cause of the course of that stream. The general east and west course of these faults, together with their tendency to open and form places of deposit of veins, shows that they are probably in some way connected with the formation of this anticlinal axis. I am inclined to think that some of the extensive series of veins, carrying galena and other substances, which have been discovered in the neighborhood of Lexington and Frankfort, traces of which are found even to the Ohio river west of Cincinnati, may possibly be regarded as in a general way connected with the movements which elevated this axis. The tendency of all axis of elevation is to open along their crest, so that the general form of a mountain chain shows us the geological hills cut down to form the geographical valleys, and the geological valleys perched upon the hills. This comes about from the action of the eroding agents, which operate much more powerfully upon rocks that are opened to the weather than upon well-compacted and condensed rocks. It is easy to see that the rocks on the top of the great stone arches will be much pulled apart; they being in no degree elastic, rents must be formed into which the destroying agents, frost and the slow decay which water brings to work on the rocks, will easily penetrate. On the other hand, the rocks in the geological valleys are compressed by the folding action, so that I believe that, given two rocks essentially similar in constitution, the eye can, in many cases, recognize the difference in mechanical condition in those two conditions of pressure. Of course the extent of this action must be measured by the amplitude of the folds. In short curves, as in the Alleghenies and most other mountains, the compression and extension are necessarily very great. In a very broad field like the Ohio axis, the extension on the top of the arch would not be very great; but it might easily result in making a number of fissures which would penetrate to a considerable depth.

The exceeding breadth of the Ohio axis, and the great uniformity of the arch, leads me to believe that the thickness of the rocks involved in the movement which produced the axis, was very much greater than usual in mountain folds. An experiment with sheets of metal, or what is better, with sheets of paper of different thickness, will show that the amplitude of such curves is proportioned to the thickness of the material to which we apply the lateral pressure. General considerations will show this to be a law common to all rigid substances subjected to a lateral pressure. If this view be correct, then the Ohio axis indicates that the lateral pressure which has formed this axis has caused the movement of a greater mass of rocks, in one body, than any other similar ridge which has yet been observed.

I have elsewhere endeavored to show that the wrinkles or folds on the earth's surface, or the movements which indicate lateral pressure, are divisible into two distinct classes: relatively narrow steep folds, which are properly mountain chains, and very broad gradually sloping arches and furrows, which constitute continental ridges and sea basins. There seems to be no series connecting these dissimilar sets of curves, and I have endeavored to show that the continental folds are probably accommodations of an outer solid shell of say one hundred miles in thickness, possibly less, to the great central mass diminished by the loss of heat; while the mountains arise from the contractions which have taken place in the outer crust itself. The great width of the Ohio anticlinal axis makes it more like a connecting link between mountain and continental upheaval than anything else I have yet seen; yet I am satisfied that it should be classed with mountain folds.

I have already discussed, in a general way, the period of formation of the Cincinnati axis, in the general account of the history of the rocks which we can observe upon its sides. We have in that history no distinct evidence as to the time when its final elevation was accomplished; but from the general want of pebbles in the rock formed during the coal period, (which is composed of materials brought from a great distance,) I am inclined to believe that it was not out of the water at the time of the latest formation known in that district, though it was probably begun at a very early age. The fact that the rivers of the Ohio system, which evidently wrestle with the Cumberland Mountains, have evidently had no great difficulty in laying their courses straight across the Ohio axis, is a striking evidence that it must have been lifted very slowly to its present height. If it had at any time been suddenly upthrown, it would have barred those rivers and compelled them to make something like the sudden southward turn which the Tennessee is compelled to make in its effort to get clear of the Cumberland chain. The Kentucky river appears to be a little troubled to pass the barrier; but I believe that this is altogether due to the influence of local faults, which cause the channel to wind about in its passage over this axis. The Cumberland river, on the other hand, avoids the geologically lowest part, and turns to cross the summit of the ridge at Nashville. These facts warrant us in supposing that the development of the ridge has been so gradual that the courses of the streams across it have never been obstructed.

At Wells' river, near Clarksville, and south of the Kentucky line, in the western section of the State, there is another axis of disturbance, which seems to be, on the whole, parallel to the Cincinnati axis, though its direction and other important features are yet to be determined. The considerable southward extension of the western coal field towards the Tennessee line, in Todd and Christian counties, can best be accounted for by supposing that a synclinal of this Clarksville axis of disturbance extends north into Kentucky; it probably also is among the disturbing influences that have greatly affected the western coal field in the region just north of this part of its border. As yet, too little is known of this field to enable us to define with precision the direction of the disturbances which have so greatly perturbed it. I am inclined to think that this Clarksville axis has been the line along which most of the dislocation has been developed.

Incidentally, I have already mentioned the appearance of something like local uplifts in the Hickman and Columbus district, where the Chickasaw bluffs give, by their peculiar isolated character, some grounds for suspecting local elevation. This is also a field where the facts are still to be collected. I am by no means satisfied of the truth of this conjecture, and shall be glad to find that these peculiar ridges are only the remains of an extensive plateau that has been nearly completely destroyed by the wandering river.

Having considered the geological accidents that have given character to the line regions of the State, we will turn now to that small but peculiarly interesting section where the subterranean disturbances are exposed in the form of mountain chains. As before remarked, this region is but a fragment of that great system of disturbances which, extending from Newfoundland to Alabama, constitutes the Appalachian mountain system. This great system affords one of the most beautiful illustrations of the action of mountain-building forces. In it the action of these forces, at far different times and upon very varied rocks, can be studied with care, without the hindrance of the exceeding structural complications found in the great Alpine system, or by the difficulties of distance which beset the student of the Cordilleras of America.

It is from the Appalachian system that we have the most to hope in the way of information as to the causes that have worked in the building of the earth's feature-lines; and it is therefore a matter of great scientific importance to have every part of this system examined in detail. The Pennsylvania Geological Survey has already given us some studies on the structure of this system; and the revived Survey, under the skillful supervision of its present able chief, will doubtless do much to extend and perfect the work; but it is in a high degree necessary that this investigation should be carried on at a number of different points along the chain; for there are about a dozen different regions along its two thousand miles of length, each characterized by some special method of manifesting the compressing forces. The Gaspé section differs from that of Northern New Hampshire and Maine. The Vermont, Massachusetts, and Connecticut regions form a third division; the Catskill, in New York, a fourth; the Alleghenies, of Pennsylvania, a fifth; the district of Virginia, between the Potomac and the Kanawah, a sixth; the section from the Kanawah to Chattanooga, a seventh, and the Alabama section, where this system of elevations fades out and passes beneath the recent beds, is to be classified by itself, making the eighth.

Parallel to this linear group we have at least half a dozen distinct, eastward, outlying ranges, having the same general direction as the Appalachian system, and entitled to be considered as a part thereof. Of these, the Nova Scotian and

Cape Breton sections are the northernmost; then come the system of Mount Desert, that of the Blue Hills and Eastern Massachusetts; then the Blue Ridge, beginning as the South Mountain in Pennsylvania and connected with the Blue Ridge in Virginia; then the Unaka section, including the highest land in the whole system of the Appalachian. Still to the east we have, in Virginia, the uplift, which I have termed the Richmond axis, where the syenite has been thrust up to form the eastern border of the Mesozoic coal field of Virginia. There are other regions of disturbance which, either by their peculiarities of structure or by the fact that they have been the product of special and limited upheavals, deserve to be given a special name. The limited disturbances of the Martha's Vineyard region, on the New England coast, dating from the time of the later Tertiaries, the Mount Tom upheavals in the Connecticut Valley, the peculiar submerged ridges of unknown age off the Carolina coast, and other local upheaval regions, could extend our catalogue of regional divisions of the Appalachian much beyond the limits of the score of divisions suggested above. It is far from my purpose to do more than indicate the general fact that there are such features as regional divisions in the Appalachian chain, and that it has been the product of many successive elevations acting along the same lines of upheaval. The existence of these successively formed elevations, all having essentially the same direction, needs to be dwelt upon, on account of the strong impression which the theory of M. Elie de Beaumont, concerning the parallelism of mountains of the same age and the diversity of direction of mountains of different ages, has made upon the minds of naturalists. I believe it important that the reader should approach the study of this field without the hampering influence of these opinions, lest the most valuable lessons which may be learned there be obscured by prejudice.

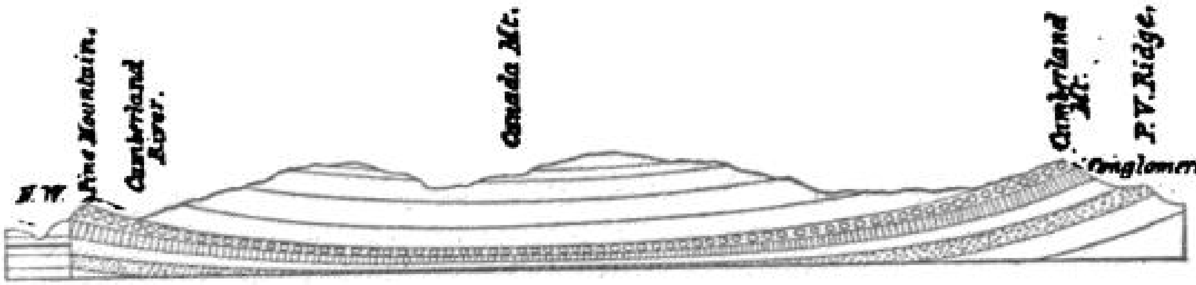
The Kentucky section of the Appalachians is so small that the studies which we are to pursue here will be limited to some of the simpler problems afforded by the Tennessee section of the Appalachians. The action of these mountain-building forces are limited in Kentucky to the region east of a line drawn from the county of Pike, on the West Virginia line, to the Tennessee line, near Jellico. This district does not include more than about five thousand square miles of territory, and only takes in the westernmost features of the Tennessee section of the Appalachian system. It has, however, in Pine Mountain, nearly the whole length of one of the most remarkable of all the mountains of this section, and between this remarkable ridge and the Cumberland Mountain, on the east, nearly one hundred miles of a great synclinal valley, which we shall call the Cumberland synclinal. In order adequately to understand this region, it will be necessary to look a little into the structure of the whole Tennessee section, and notice its relations to the neighboring districts. Enough is known of the structure of the Allegheny or Pennsylvanian section of the Appalachian to make it clear that it is composed of a number of parallel ridges and furrows, lying side by side, so that the east and west section is like a cut across a piece of corrugated roofing. This structure may be called the normal structure of a mountain of simple folds. In it there are few great north and south faults, and they rarely come in to break up the symmetry of the great folds. These folds do not average more than four or five miles in width, and are generally sufficiently distinct to make their original outlines quite recognizable. The decay at the top of the arch, favored by the open structure which, as we have seen, leads to such rapid destruction of mountain arches, has not in Pennsylvania gone further than it has in the Swiss Jura, and the mountain has been, in many cases, simply opened to the action of the air, which has not yet done great destruction.*

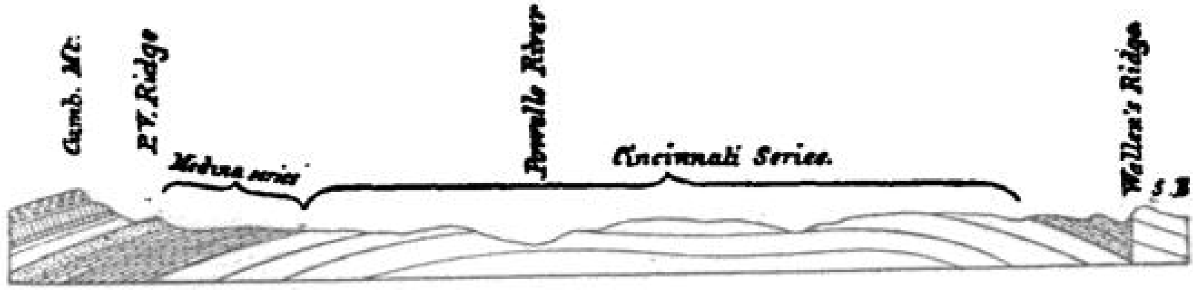
In East Tennessee the conditions, as indicated by the structure of the rocks, is something quite different from that of

*The slight amount of this wearing action in the case of the Pennsylvania mountains, as, for instance, in the Blue Mountain, has led me very much to doubt that the whole of that section has been elevated in times as remote as the Trias. I cannot believe that we could have had the whole of some protecting formation swept away from the flanks of these mountains while the arches have worn down so little. I should feel that the Blue Mountain had not suffered as much by erosion as many mountains of Tertiary age have done. I cannot, indeed, see much more wear indicated by the Blue Mountain, for instance, than in the Puy de Dome, or the other relatively recent volcanoes of Auvergne, in Central France.

Pennsylvania. That we may see these conditions clearly, let us glance at what were the probable circumstances of this region when the formation of the mountains began. There is very little doubt that this district was generally, if not uniformly, covered by the beds of the Carboniferous period. These abutted on the east against the great Unaka Island, then probably covered by beds of a later age than those now exposed there. When the movements of the uplift began, time does not show the pebbles of the old granitic rocks now exposed thereon. When the movements of the uplift began, this ancient island would naturally yield less than the low-lying beds on either side. It seems to have acted as the Blue Ridge has acted throughout its length, to confine the movement to the regions west of its mass. Whatever motion was given to it, probably followed the ancient lines of fracture, which may exist within it; but they did not result in making typical arches of the Allegheny forms.

The movements on the west of the Unaka axis seems, at first sight, quite unlike the ordinary Alleghenian dislocations. If the geologist looks from the summit of the Cumberland Mountains over the far-extending mountain region of East Tennessee, he beholds line upon line of bold rocky walls, which fill the field of view. Away to the east the Unaka range, and the neighboring mountains of North Carolina, bound the horizon with a high, serried range of crests, whose varied outlines contrast strongly with the even ramparts of the newer ridges of the Tennessee Valley. Looking closely at these ridges, we find that, with the exception of the Cumberland range, they are one and all produced by the action of faults; and their lines indicate the existence of a wonderful series of breaks, extending for a distance of more than one hundred miles in some cases, and, in more than one instance, of singular uniformity of height. In the whole section there is but one distinct anticlinal—that on which the ridges of Cumberland Mountain stand—and one distinct synclinal—that through which the Cumberland river flows in that part of its course which lies above Pineville. The structure can best be explained by supposing, that, in the elevation, the tendency was to form a great anticlinal some fifty or sixty miles across, and that it was unable to support itself, and the sides of it fell, in a succession of longitudinal strips detached by the parallel faults; and the only part retaining the anticlinal character being the section of which Cumberland Mountain is a part. The eastern retreat escarpment has been destroyed by faulting. It will be seen by the diagram given below that this escarpment has retreated a great distance from the central axis of the anticlinal, being several miles back from that line:





It is a striking fact, that there are no outliers of the riven beds scattered over the mountain valleys. Several of the walls of the faults have worked back some distance from the point of fracture; but in most cases they are still close to the point where the break was formed. This is most conspicuously the case in the Pine Mountain, which, throughout its whole length, has its escarpment within a few hundred feet of the break where it was first found. It is only necessary to consider what is going on along the faces of cliffs, such as are exposed on the steep walls of Cumberland or Pine Mountains, to be convinced that the process of retreat, under the action of eroding agents, must be exceedingly rapid. The steep angle of the slope, the inclination of the beds, the universal presence of a cutting stream, led in towards the cliff by the inclination of the strata, all combine to make the erosion go on with great rapidity. The retreat of one of these escarpment faces, when the angle of slope is kept at over twenty degrees of declivity, must be many times faster than the ordinary wear of the country. As this average erosion rate cannot be less than one foot in 3,500 years in this region, we cannot reckon the retreat rate of these faces at less than one foot in one thousand years.* Everything favors a rapid wear—the great rain-fall, great action of the frost, and the decomposable nature of the materials.

I find it difficult to believe that the present rate of retreat of the escarpments of Pine Mountain is as slow as that given; but, even at this rate, the retreat would be one thousand feet in a million years; and the estimated duration of the Tertiary time, which by no reckoning is made less than four or five million of years, would cause a retreat of these erosion cliffs about a mile in distance from these points of origin. On Pine Mountain, at several points examined, there was not one half of this distance between the summit of the cliff and the downthrow side of the fault. What makes this the more re-

* The erosion rate is determined by the following co-efficients, the amount of rain-fall and frost action, the resistance of the materials due to their composition, and the attitude of the surface.

markable is, that this fault, like all others, is not vertical, but probably has a considerable dip in the same direction as the slope of the escarpment.

When we look at the Cumberland anticlinal, swept clean of its upper beds for a width of many miles, and then compare it with the Pine Mountain fault, we are driven to the conclusion that the formation of the fold must far ante-date the existence of the fault. The same argument will convince us that many of the other faults in this section of the Appalachians are to be regarded as belonging to a relatively late time, though I have seen no such proof of newness as Pine Mountain affords. It is in a high degree desirable that accurate sections on a true scale should be made across the section between the Unaka Mountains and the western border of the Appalachian disturbances, with a view to getting accurate information on this subject.

The existence of these relatively modern breaks in this ancient chain requires us to suppose the continuance of disturbances down to a very late date. All the subsequent disturbances seem to have taken the shape of faults rather than folds. The cause of this is uncertain; but, without entering upon an attempt at an explanation, I would say, that I find in my notes, made during a year of journeying in Switzerland, in 1866–'7, the frequent remark, that the Alps were completely girdled by just such a belt of faults as we have here. Subsequent studies on mountains have satisfied me that there is some necessary connection between the occurrence of faults and the action of this mountain-building force in the immediate neighborhood of an ancient and massive mountain region. The effect of mere weight on the development of those curves of the crust, and the possibility of their formation being arrested or modified by weight alone, is very well shown in the condition of the Cumberland anticlinal, as it, in its southward extension, comes against the massive Tennessee table-land, where, as my learned friend, Dr. Safford, has shown me, the thickened and little worn beds of the lower coal measures, conglomerates in the main, have proved too massive to be involved in the mountain-building movement. If the fold had kept its course, it would have had to crumple this mass into its curves; but it seems to have been turned abruptly to the east and shortened to half its breadth, if not quite extinguished.*

An interesting inference, as to the ancient conditions of this district, can be made from this effect of the Tennessee table-land on the course of the Cumberland anticlinal. This inference is, that this table-land has existed, in something like its present relative thickness, from a very ancient time. If many thousand feet in thickness of beds had been removed from this country since the formation of this anticlinal, the chance of this table-land having its relatively massive structure would not be great. This is an argument for the relatively recent origin of this part of the Appalachian system. The Pine Mountain fault, also, disappears against this massive fragment of the ancient carboniferous table-land.

The great synclinal of the Cumberland lies, for most of its distance, within the State of Kentucky, its western boundary being the unbroken line of the Pine Mountain, its eastern side being bounded by the slope of the Cumberland anticlinal. This synclinal is by no means a simple, unbroken trough, but is filled with minor but most interesting accidents in the shape of cross-faults and transverse axes of elevation. In the neighborhood of Cumberland Gap, these transverse faults and axes give a most complicated geological structure. At a point about midway of the valley, on a line from Pineville to the Gap, we have a beautiful example of a half dome, formed by an arched upthrow on one side of a fault, known as Rocky Face.†

Many of these faults pass completely through the Cumberland escarpment, or Cumberland Mountain, as it is commonly called. Cumberland Gap is formed by the erosion caused by

*This wonderful section deserves, and should receive, the most careful study from our American geologists. I have seen only enough to fill me with desire to learn more as to its structure. I am sure it is more likely to reward the student of dynamic geology than any other district known to me in the whole Appalachian chain.

†Some of these accidents are two complicated for description, and we must await the making of the final map of the district in order to represent them in any adequate fashion. The want of such map compels me to omit all mention of the details of structure in this most interesting region.

one of these faults, which traverses the ridge in an oblique manner, the downthrow being on the west side of the fault line. A mile further, to the southeast, apparently on the continuation of the same fault line, we find another evidence of faulting in what is called Double Mountain. Here, again, the crest has retreated but very little from the fracture line, showing the recent character of the break, which must, indeed, have happened long after the topography had taken on its present general character. It seems likely that the series of breaks, which opened the passage of the Cumberland through the Pine Mountain at Pineville, formed the half dome at Rocky Face, cut the Cumberland Mountain at the Gap, and formed Double Mountain, are either on one and the same fault line, or constitute a series of faults closely related in direction.

Following the line of the Cumberland to the south, as far as Big Creek Gap, about forty miles from the Cumberland Gap, we come upon an exceedingly interesting portion of the mountain. The usual dip of the beds in the mountain is from thirty to forty degrees of declivity. It is noticeable, along the sixty miles of its length that I have seen, that the direction of the mountain, as determined by its rate of retreat, varies with the angle of dip. Where the dip is steep, the mountain has retreated rapidly to the west, and the crest is low; where gradual, there is almost always a salient angle to the east, and the crest of the ridge is high. At the Big Creek Gap, however, the whole section, from the base of the Cincinnati Group to the base of the Conglomerate, is positively on end, so that the whole of this section can be crossed in traveling a distance no greater than its thickness; yet the line of the mountain is not perceptibly deflected from its general trend. At Pennington's Gap, as shown by the reconnoissance of Assistant Moore and Messrs. Davis and Eldridge, students of the Summer School of Geology, made in 1875, the same arrangement occurs. In the case of the former of these two localities, at least, I am satisfied that the dislocation has taken place, since the general trend of the escarpment has been essentially the same as it is at present, otherwise the uniformity of the alignment of the whole ridge could not have been brought about. It would have been quite impossible to have had the conditions just what they are at present, if this structure existed here before the retreating escarpment came to occupy its present place. The coincidence of water gaps through the Cumberland, at the two points where these vertical sections occur, is also remarkable, and points to the conclusion that they have been brought about by a profound system of faulting. These faults show, at several points, something of the conditions under which they have been formed, and, in order to understand their structure, it will be necessary to consider the classification of faults in respect to some of their more important phenomena. In the first place, as regards their rapidity of formation, faults may be divided into two groups: those which are formed with exceeding slowness, so that a stream flowing across the fault may not have been interrupted in its course, though the fault may have grown to a great height, the cutting action of the stream in this case being far more rapid than the rise of the fault. A second group will include those faults where the action has taken place with suddenness, so as greatly to affect the neighboring rocks, often crushing them for considerable distances from the fault line.

So far as my observations go, it appears as if the great North and South faults, such as those of Pine Mountain and Clinch Mountain, had been of tolerably gradual formation, though I do not think they have been upheaved so slowly that the rivers have not been turned aside from their courses; but they do not have the appearance of violence that belongs to the transverse faults. The smaller faults, which cross the others at various angles, show at several points, by the breccias that occur along their lines, the violence that attended their formation. The Cumberland Gap fault, for instance, is traceable by a belt of breccia, of ten or more feet wide, that marks its line. This breccia is composed of bits of conglomerate sandstone, with ragged angles, fixed together by oxyde of iron. So far as I am able to judge, these bits of stone are all from the rocks in which they are bedded, being rarely more than broken to pieces by the motion, and not greatly displaced from their original positions. On the southwest side of this fault, at Cumberland Gap, there is a downthrow of several hundred feet, probably about three hundred, and the beds only gradually recover their place in the face of the mountain after about a mile of distance.

In the Cumberland synclinal, we have evidence of the extreme difficulty which these mountain-building forces had in throwing this surface into folds. This valley, which is about ten miles wide, is almost level throughout this width, and only shows the crumpling action near its borders. The section published with this report does not show all the peculiarities of this singular valley, the details of the small disturbances being quite left out. I believe that this level character is due to the same causes that made the Tennessee table-land completely arrest the Cumberland anticlinal. This cause is either to be found in the thickness of the section or the thickness of the mountain-building forces. As we go south into the Tennessee table-land, we find in the Sequatchie Valley, as was admirably described by Professor J. M. Safford, in his lectures at the Summer School of Geology, in 1875, a complete mountain ridge in the midst of this great area of undisturbed rocks, with great areas of horizontal beds on either side.

Looking at the general section of the Cumberland escarpment, or mountain, as it is called, we notice that the dip of the beds becomes suddenly great at that point, and that there is comparatively little dip on either side. This peculiarity has suggested to me the hypothesis that, possibly, the time of the formation of the Pine Mountain, and probably some other faults, was one of renewed lateral pressure, and that this escarpment, which is separated from the high land of the synclinal, along its whole length, by the valley, had its dip suddenly increased, the whole of the dips in the anticlinal valley being also increased by the movement. I am the more inclined to accept this hypothesis, because the continuation of the present dip lines would carry the arch of these eroded mountains to a great height—a height greater than I am inclined to suppose they ever had. But the strongest argument for some such supposition is, the coincidence of the occasional vertical dip with the escarpment line. As the rate of retreat of an escarpment is, on the whole, proportionate to the angle of declivity of the beds, being greater with steeply inclined beds than with horizontal beds, there seems little reason for finding this coincidence here, unless it came in the way indicated.

Another point, which gives me trouble to explain, is the relatively intense wear of the disturbed region. After allowing much for the effect of the opening of the rocks caused by their dislocations, there remains evidence of a very excessive erosion. It seems to me there should be more of the coal-bearing series of rocks in the disturbed district of the East Tennessee section than actually remains there. It is likely that this excessive erosion has been, in the main, caused by the powerful river system of this section. It only requires a glance at the map to show that we have there a great engine of erosion in the branches of the Tennessee river, effective at the present time, and probably doubly powerful in the early day, when they were fed from the then far higher lands of the Unaka Island, before they were worn down to their very roots by erosion. It is also possible that this region has been swept by ice streams from this mountain centre on the east, for the erosion is somewhat after the fashion of the wearing which has dug out the basins of the great lakes, when the ice sheet from the Laurentian mountain system came down upon the softer rocks. The East Tennessee river system exposes that region, at the present day, to the most rapidly wearing of any part of this continent. These rivers have considerable fall, and are fed by a rain-fall of at least sixty inches per annum.

Throughout the Eastern Kentucky coal field there are slight indications of dip in various directions, which cannot be reduced to any distinct system. On dip map in Assistant Crandall's report, in the second volume of this series, is a good representation of the variety of these inclinations as regards direction and angle. After a good deal of consideration, I am inclined to abandon the idea of these irregularities being the result of dislocatory forces. In many cases, at least, they are doubtless due to the difference in thickness of subjacent beds. Both the Sub-carboniferous limestone and the Conglomerate vary greatly in their thickness. This is in a measure true of many sections of the coal beds, so that the beds laid down on these variable measures will necessarily vary a good deal in their inclination. The erosion, whenever it is subterranean—and it has this character wherever there are limestones above the drainage—is sure to give rise to many local dips. This is also occasionally the case in localities where there are clays which can be leached of their saline matters by the action of the penetrating waters. A very large number of minor dislocations, in Western Kentucky, are doubtless due to the sinking of extensive cavern areas.

The strongest objection to the classification of the many minor irregularities of dip, as due to lateral pressure, is, that we require this lateral pressure to act in the very outermost beds of the crust, and we fail to find any sign of the regular arrangement of the folding in determined axes, which is so constant a feature in all cases where we have distinct evidence that the disturbances have been caused by mountain-building forces.

The only permanent feature, in the generally irregular dips of the region west of Pine Mountain, is the southeastwardly inclination of all the beds. This inclination is very general though slight. From time to time it changes to a northwestern direction, so as to lead me to conjecture that there might be a faint trace of anticlinals parallel to the Allegheny axes; but I have not been able to get any distinct evidence on this point. It will not be until the whole of this section is accurately mapped, and the dips indicated thereon, that we shall have any basis on which to determine this hypothesis.

Summing up the history of the dislocations in this section, we see that the whole of Kentucky, and, in fact, the whole of the section included in the Ohio Valley, is in the grip of those movements which have been building the Appalachians from the earliest beginnings of the continent. The section of this system which lies between the North Carolina district on the one side, and the Cincinnati axis and Tennessee table-land on the other, differs from the Allegheny section in the fact that faults have, to a great extent, taken the place of folds. These faults in some, if not in all, cases, must be regarded as of very recent age, from the fact that their escarpments have not retreated for any distance from their original position at the time of formation of the fault. The folds, at least that of the Cumberland Mountain, are of a date far more ancient than the neighboring faults. Furthermore, that the great erosion of this district can be, in part, at least, accounted for by the extensive river system confined in this district by the general structure of the country, and concentrating on it the erosive force of the great rain-fall, which the Unaka Mountain system, as well as its own high ranges, must have given to it ever since an early time in the history of the continent; and also, that the curious local disturbances of the beds along the Cumberland escarpment can be attributed to the fact that the difference of weight at this point, between the low-lying plain and the mountain section, caused breaks to be made along its line, from which line the erosion has not been great enough to work back the escarpment since the time when these last disturbances occurred.

We will now consider the action of the forces which come from the earth's interior, in the shape of those tremulous movements which we term earthquakes. It will be seen, in the sequel, that this State has a special interest in this class of actions, having been the seat of the most remarkable series of such disturbances, which has affected this continent within the historic period.

In our ignorance of the cause of earthquake movements—an ignorance which has only begun to be diminished by the latest researches in seismology of Mr. Charles Mallet and others—we have been driven to group under one name phenomena, doubtless, of the most varied origin. There can be little doubt that these disturbances of the earth are of as various origin as the movements of the air; but to our senses everything is absolutely hidden, except the movement consequent on these varied accidents, and this movement is made uniform in all its features by the laws connected with the elasticity of the earth. The admirable researches of Mr. Charles Mallet have shown us that the earthquake of 1851, in Calabria, and one or two other disturbances, have probably been caused by the sundering of the rocks and the opening of a fissure having a length of many miles and a depth of many thousands of feet, the topmost part of which was about fifty thousand feet below the surface of the earth. This determines one of the sources of disturbance, and undoubtedly this is a very frequent cause of great movements within the earth. The exceedingly great number of these breaks within the earth's crust, which we know to have been formed in the past, gives us an assurance that they are an essential feature in the economy of the earth; so it is quite warrantable to suppose that they may be formed at any time in the earth's history, and at any point beneath its surface. In the cases where there has been good reason to suspect that the formation of rents has been the cause of the earthquake, the area of the regions shaken and the magnitude of the disturbance were both quite small. It is not probable that the vast convulsions which have shaken great continents, or those peculiar disturbances which have given us continued shocks such as we shall now have to consider, were due to the same sort of causes. Our study of the phenomena of the earth makes it sure that change in bulk is one of the most frequent and efficient causes of disturbances. After we get a few hundred feet below the surface, there is probably no part of the mass which is not impelled by powerful forces to either expansion or contraction. When the mass of the material affected by these tendencies becomes sufficiently great, some alterations must take place. It is by no means necessary that these movements shall affect the surface of the earth in any permanent way. The outer few thousand feet of strata may not be disposed to movement, or may be so rigid that the lower shiftings cannot drag it into their own movements; but the result may be accomplished by a compression of beds at some other point.

I am inclined to believe that these earthquakes, which are characterized by a great and long-continued succession of shocks, occur more commonly in regions remote from recent mountain chains, where the evidence is that the mountain-building forces are at rest, than in the midst of a mountain region where the mountain-building forces may be presumed to be still active. If this be the case—and, after some search through the history of earthquakes in the tables of Perry, of Dijon, Mallet, and others, I have not found a clear exception—then we have something like a confirmation of this hypothesis, which is substantially that adjustments may be effected in either of two ways—by the interior slipping on the exterior, or by the exterior contracting to allow the interior freely to take its adjustments.

There are, I believe, at least three distinct classes of sub terranean disturbances which are likely to produce earthquake shocks:

1st. The contraction of rocks forming crevices which may be filled by molten matter forming dykes, or, in other cases, by the slower action of heated water, constituting veins.

2d. The slipping of rocks over each other under the influence of compressing forces, giving phenomena such as may be observed in mountain chains.

3d. The sudden movement of gases contained within the earth, impelled by great heat to the exercise of sufficient energy to dislocate the rocks that contain them. This last class of causes is probably operative only in the vicinity of points of volcanic activity.

The Ohio Valley has been the seat of repeated slight earthquakes—too slight to demand notice, save as evidences of the existence of earthquake-making fissures. All of these shocks seem to have originated beneath this valley. But a single series of shocks in its whole history have had the violence of a great convulsion impressed upon them. In November, 1811, began a series of convulsions unequaled, or, at least, unsurpassed, by any earthquakes which have been felt upon this continent. These memorable events are known commonly under the name of the earthquakes of New Madrid, that town on the Mississippi river, opposite the extreme southwest corner of Kentucky, being the most important village within the range of its devastations. In Appendix B I have brought together some information concerning this catastrophe, which may be consulted by the reader desirous of acquainting himself with the general character of the convulsion, and its most important effects. In this Appendix will be found the admirable statement of Judge Fowler, of Livingston county, who seems to have retained, in a very clear way, the impressions made by the events of those days. His account of the invention of the frontiersman for observing the shocks is very interesting, as it furnishes probably the first record of a pendulum apparatus for observations of this description.

The records of this early event in the history of this valley are extremely imperfect in a scientific point of view, and yet sufficient to assure us that the convulsions, for the first part of the disturbance, were of the most violent character. Occurring at the present time, there is no doubt that they would cause a terrible loss of life and property throughout the region where their action was most violent. The only fact bearing on the range of this shock not given in the Appendix is, that, at the town of Leitchfield, in Grayson county, several chimneys of great solidity were overthrown almost to the base.

As this convulsion was so terrible in its character, ruining even the log cabins of that early day, at the points where its action was most severe, it becomes a matter of importance to see what light, if any, can be thrown on the probability of its re-occurrence in this region. Although no certainty, or anything approaching it, can be obtained on this point in the present state of the science of earthquakes, it seems to me that there are some points which are not without value in helping us to a judgment as to the probability of a return of the catastrophe.

In the first place, it must be observed that the occurrence of a great convulsion, away from centres of volcanic activity, and remote from mountains which exhibit recent disturbances, is exceedingly rare. The great alluvial regions—the regions of far-reaching horizontal stratification—have never, save in this single instance, been visited by a great convulsion of this kind, although they occupy quite one half of the earth's surface, or at least of that part which is within the historic belt. No such convulsion, nor any considerable earthquake, had occurred in the hundred and fifty years which had passed since the country came within the observation of travelers. The French explorers would probably have found some accounts of such a catastrophe, in the traditions of the Indians, on whom, as on all rude peoples, such events make a very strong impression. Great earthquakes, like deluges and other destructive natural accidents, become woven in with the traditions of a people, and preserved for centuries. Over three score years have passed, and the trifling shocks which have been felt in this valley have been, one and all, isolated shocks, and had nothing like the serial continuity which belonged to the disturbances of 1811–'13; so that, for hundreds of years before, and for three fifths of a century since this disturbance, there has been nothing like a renewal of the movements. A still better argument for the rarity of this accident in this section is found in the exceedingly extensive disturbances which it caused in the beds bordering on the Mississippi. It is one of the results of a great convulsion of the earth to discharge the tensions near the surface in the region where it occurs. Rocks almost ready to fall, but the fall of which might be distributed over centuries, come down in confusion together. Pent-up gases, which would be slowly discharged, are thrown out at once, and in other ways unstable equilibriums are adjusted. In the region bordering on the Mississippi, a prodigious number of land-slips, crevices in the earth, and sand-blows or outpourings of gas driving sand before it, took place, all tending to show that the tensions which were discharged were very great in number, and probably had not been released for a very long time by any similar convulsion. Altogether, the evidence looks towards the conclusion that a great disturbance of this kind is quite out of the natural order of events, and may be so exceptional as not to be expected to occur again for any reasonable time in the future.

It is an exceedingly interesting fact that the centre of these oscillations, or seismic vertical, as it is called, seemed to move from the region about New Madrid in an easterly direction, during the continuance of the disturbances. At the end of the series of movements, in 1813, it seems to have been nearly one hundred miles to the east of its position at the beginning of the convulsions. It seems to me that this may have a bearing on the theory of that class of earthquake disturbances when the movements take the form of successive movements occurring in a serial order. I am inclined to believe that they are not produced by the formation of faults, but by the slipping of deep-seated rocks on each other, in the effort to adjust the strains which had developed within them. This gradual eastwardly movement looks like a transfer of the slipping action gradually towards the Cincinnati axis, where the mountain-causing forces have been satisfied by the elevation of a great ridge. I only suggest this conjecture, because it seems to fall in with the theory that these continued tremblings are connected with a slipping movement of deep-seated beds.

It may not be out of place to notice, that the extensive development of very old and very extensive caverns, in the central district of the State, in which there are few indications of any violent actions which cannot be explained without the intervention of earthquakes, is something of an argument on this point, though I doubt if we can determine its precise value. There is a fact, however, in this connection, which may have some value. I have noticed in the Mammoth Cave, Salts Cave, and other caverns in the Edmonson district, that beneath the stones in many avenues we can find a great many bits of charcoal remains of the ancient torches. It is claimed by the guides, that, since the modern extensive visiting of the

Mammoth Cave, the fall of a single stone has not been noticed. The quantities of stone, with chips of charcoal beneath them, requires us to suppose, either that the Indians have been entering these caverns from a time of very great antiquity, or that there has been some convulsion which brought down quantities of stones at one time. There is nothing to show that the earthquake of 1811 may not have done this; but a somewhat careful inquiry among the early settlers has failed to give me any observations on changes made within our caverns by that disturbance. It should be noticed, however, that they were but little entered in those days.*

Before leaving the study of the forces which lead to movements of the earth's crust, I must call the attention of observers to some obscure indications which may, or may not, be connected with changes of level within the State. In the neighborhood of Pine Mountain, on the head waters of the Cumberland, the streams very generally have the character of extremely sluggish, swamp-bordered channels. At every other point observed by me in the Appalachians, the mountain streams have shown a considerable fall, usually not less, for terminal streams, than three or four feet per mile. Yellow Creek, Marshy Creek, and, in fact, about all the smaller tributaries of the Cumberland on the west and south sides, have more or less of this swampy character. We frequently find that, for many miles, the stream will not touch its rock-bed, and is clearly quite incapable, on its present position, of cutting out the valley in which it runs. I have been driven to the hypothesis that, since these valleys were formed, there has been some change of level which has diminished their cutting power.

Marsh Creek, in Wayne county, about 12 miles east of the Cincinnati Southern Railway, and the other creeks having a similar position, would have their peculiarities accounted for by supposing a sinking of the beds on the west side of the

* Although the caverns were somewhat used for making saltpetre, they were little explored by the early settlers until the Mammoth Cave began to be resorted to by travelers from a distance.

Pine Mountain fault, amounting to, say, twenty or thirty feet, the subsidence becoming less and less as we went further and further from the fault. Yellow Creek Valley, which is in the synclinal trough, is not so easily explained. I believe that it is quite incapable of cutting out its valley at the present time. Over a large part of its course it has no wearing action against the sides of the valley; yet, with its feeble stream, it has worked down at least two hundred feet lower than the general surface of the Powell Valley, on the other side of the Cumberland Mountain. The only way in which I can account for this loss of cutting power, is by supposing that the latest movements, which must have been exceedingly near the present time, increased the barrier which separates this stream from the lower waters of the Cumberland, or possibly actually depressed the synclinal so as to make the trough lower than it was before.

It may be said that the movements, necessary to bring about these changes of level, would necessarily have left some more conspicuous mark on the line of the fault than exists at present. I do not attach much importance to this objection, for the amount of movement required is probably not more than fifty feet; and this can be supposed to have occurred without causing any evident disturbance along the line of fault. This line is obscured by a great mass of talus material; and this would effectively hide all the changes which would be brought about by a few feet of movement.

I have been forced to the conclusion that all mountain ranges, where the mountain-building forces are still active, the movements dependent on their continued changes of weight are almost incessant. I can accept no other view than that continents and mountains are, on the whole, in a state of unstable equilibrium. The forces which lifted them having acted to that point where they were just balanced, the weight and the forces that tended to raise up were equal with the forces that tended to bear down. The loss of weight through erosion would naturally be attended by a continued slight movement of re-adjustments, and the increase of strains from the loss of heat in the crust would likewise be attended by the change of tensions. On this ground of constant slight changes, the peculiar relations of some of these valleys can be well explained.

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APPENDIX A.

The following pages are taken from the admirable work of Hon. Geo. P. Marsh, which is better known by its first name of "Man and Nature," than by the title of the second edition, "The Earth as Modified by Human Action."* The Commonwealth of Kentucky is indebted to the illustrious author for the permission he has given me of making these limited extracts from his extended treatise.

It is my duty to call the attention of the reader to the fact that the following pages, shorn of their context, give a very inadequate idea of the author's treatment of his subject. His treatise is the great masterpiece among the many essays that have been written upon this subject, and should be read by all who desire to understand the effects of man's action on our earth's history:

Extracts from the Earth as Modified by Human Action, by George P. Marsh.

"INUNDATIONS IN WINTER.

"In the Northern United States, although inundations are not very unfrequently produced by heavy rains in the height of summer, it will be found generally true that the most rapid rise of the waters, and, of course, the most destructive 'freshets,' as they are called in America, are occasioned by the sudden dissolution of the snow before the open ground is thawed in the spring. It frequently happens that a powerful thaw sets in after a long period of frost, and the snow which had been months in accumulating is dissolved and carried off in a few hours. When the snow is deep, it, to use a popular expression, 'takes the frost out of the ground' in the woods, and, if it lies long enough, in the fields also. But the heaviest snows usually fall after midwinter, and are succeeded by warm

*The Earth as Modified by Human Action, a new edition of Man and Nature, by George P. Marsh: New York, Scribner, Armstrong & Co., 1874.

rains or sunshine, which dissolve the snow on the cleared land before it has had time to act upon the frost-bound soil beneath it. In this case, the snow in the woods is absorbed as fast as it melts, by the soil it has protected from freezing, and does not materially contribute to swell the current of the rivers. If the mild weather, in which great snow-storms usually occur, does not continue and become a regular thaw, it is almost sure to be followed by drifting winds, and the inequality with which they distribute the snow over the cleared ground leaves the ridges of the surface-soil comparatively bare, while the depressions are often filled with drifts to the height of many feet. The knolls become frozen to a great depth; succeeding partial thaws melt the surface-snow, and the water runs down into the furrows of ploughed fields, and other artificial and natural hollows, and then often freezes to solid ice. In this state of things, almost the entire surface of the cleared land is impervious to water, and from the absence of trees and the general smoothness of the ground, it offers little mechanical resistance to superficial currents. If, under these circumstances, warm weather accompanied by rain occurs, the rain and melted snow are swiftly hurried to the bottom of the valleys and gathered to raging torrents.

"It ought further to be considered that, though the lighter ploughed soils readily imbibe a great deal of water, yet grass-lands, and all the heavy and tenacious earths, absorb it in much smaller quantities, and less rapidly than the vegetable mould of the forest. Pasture, meadow, and clayey soils, taken together, greatly predominate over sandy ploughed fields, in all large agricultural districts, and hence, even if, in the case we are supposing, the open ground chance to have been thawed before the melting of the snow which covers it, it is already saturated with moisture, or very soon becomes so, and, of course, cannot relieve the pressure by absorbing more water. The consequence is, that the face of the country is suddenly flooded with a quantity of melted snow and rain equivalent to a fall of six or eight inches of the latter, or even more. This runs unobstructed to rivers often still-bound will thick ice, and thus inundations of a fearfully devastating character are produced. The ice bursts, from the hydrostatic pressure from below, or is violently torn up by the current, and is swept by the impetuous stream, in large masses and with resistless fury, against banks, bridges, dams, and mills erected near them. The bark of the trees along the rivers is often abraded, at a height of many feet above the ordinary water-level, by cakes of floating ice, which are at last stranded by the receding flood on meadow or ploughland, to delay, by their chilling influence, the advent of the tardy spring.

"Another important effect of the removal of the forest shelter in cold climates may be noticed here. We have observed that the ground in the woods either does not freeze at all, or that if frozen it is thawed by the first considerable snow-fall. On the contrary, the open ground is usually frozen when the first spring freshet occurs, but is soon thawed by the warm rain and melting snow. Nothing more effectually disintegrates a cohesive soil than freezing and thawing, and the surface of earth which has just undergone those processes is more subject to erosion by running water than under any other circumstances. Hence more vegetable mould is washed away from cultivated grounds in such climates by the spring floods than by the heaviest rain at other seasons.

"In the warm climates of Southern Europe, as I have already said, the functions of the forest, so far as the disposal of the water of precipitation is concerned, are essentially the same at all seasons, and are analogous to those which it performs in the Northern United States in summer. Hence, in the former countries, the winter floods have not the characteristics which mark them in the latter, nor is the conservative influence of the woods in winter relatively so important, though it is equally unquestionable.

"If the summer floods in the United States are attended with less pecuniary damage than those of the Loire and other rivers of France, the Po and its tributaries in Italy, the Emme and her sister torrents which devastate the valleys of Switzerland, it is partly because the banks of American rivers are not yet lined with towns, their shores and the bottoms which skirt them not yet covered with improvements whose cost is counted by millions, and, consequently, a smaller amount of property is exposed to injury by inundation. But the comparative exemption of the American people from the terrible calamities which the overflow of rivers has brought on some of the fairest portions of the Old World, is, in a still greater degree, to be ascribed to the fact that, with all our thoughtless improvidence, we have not yet bared all the sources of our streams, not yet overthrown all the barriers which nature has erected to restrain her own destructive energies. Let us be wise in time, and profit by the errors of our older brethren!

"The influence of the forest in preventing inundations has been very generally recognized, both as a theoretical inference and as a fact of observation; but the eminent engineer Belgrand, and his commentator Vallès, have deduced an opposite result from various facts of experience and from scientific considerations. They contend that the superficial drainage is more regular from cleared than from wooded ground, and that clearing diminishes rather than augments the intensity of inundations. Neither of these conclusions appears to be warranted by their data or their reasoning, and they rest partly upon facts, which, truly interpreted, are not inconsistent with the received opinions on these subjects, partly upon assumptions which are contradicted by experience. Two of these latter are, first, that the fallen leaves in the forest constitute an impermeable covering of the soil over, not through, which the water of rains and of melting snows flows off, and secondly, that the roots of trees penetrate and choke up the fissures in the rocks, so as to impede the passage of water through channels which nature has provided for its descent to lower strata.

"As to the first of these, we may appeal to familiar facts within the personal knowledge of every man acquainted with the operations of sylvan nature. Rain-water never, except in very trifling quantities, flows over the leaves in the woods in summer or autumn. Water runs over them only in the spring, in the rare cases when they have been pressed down smoothly and compactly by the weight of the snow—a state in which they remain only until they are dry, when shrinkage and the action of the wind soon roughen the surface so as effectually to stop, by absorption, all flow of water. I have observed that when a sudden frost succeeds a thaw at the close of the winter, after the snow has principally disappeared, the water in and between the layers of leaves sometimes freezes into a solid crust, which allows the flow of water over it. But this occurs only in depressions and on a very small scale; and the ice thus formed is so soon dissolved that no sensible effect is produced on the escape of water from the general surface.

"As to the influence of roots upon drainage, we have seen that there is no doubt that they, independently of their action as absorbents, mechanically promote it. Not only does the water of the soil follow them downwards, but their swelling growth powerfully tends to enlarge, not to obstruct, the crevices of rock into which they enter; and as the fissures in rocks are longitudinal, not mere circular orifices, every line of additional width gained by the growth of roots within them increases the area of the crevice in proportion to its length. Consequently, the widening of a fissure to the extent of one inch might give an additional drainage equal to a square foot of open tubing.

"The observations and reasonings of Belgrand and Vallès, though their conclusions have not been accepted by many, are very important in one point of view. These writers insist much on the necessity of taking into account, in estimating the relations between precipitation and evaporation, the abstraction of water from the surface and surface-currents, by absorption and infiltration—an element unquestionably of great value, but hitherto much neglected by meteorological inquirers, who have very often reasoned as if the surface-earth were either impermeable to water or already saturated with it; whereas, in fact, it is a sponge, always imbibing humidity and always giving it off, not by evaporation only, but by infiltration and percolation.

"The remarkable historical notices of inundations in France in the Middle Ages collected by Champion* are considered by many as furnishing proof that when that country was much more generally covered with wood than it now is, destructive inundations of the French rivers were not less frequent than they are in modern days. But this evidence is subject to this among other objections: we know, it is true, that the forests of certain departments of France were anciently much more extensive than at the present day; but we know also that in many portions of that country the soil has been bared of its forests, and then, in consequence of the depopulation of great provinces, left to reclothe itself spontaneously with trees, many times during the historic period; and our acquaintance with the forest topography of ancient Gaul or of mediæval France is neither sufficiently extensive nor sufficiently minute to permit us to say, with certainty, that the sources of this or that particular river were more or less sheltered by wood at any given time, ancient or mediæval, than at present.† I say the sources of the rivers, because the floods of great rivers are occasioned by heavy rains and snows which fall in the more elevated regions around the primal springs, and not by precipitation in the main valleys or on the plains bordering on the lower course.

"The destructive effects of inundations, considered simply as a mechanical power by which life is endangered, crops destroyed, and the artificial constructions of man overthrown, are very terrible. Thus far, however, the flood is a temporary and by no means an irreparable evil, for if its ravages end here, the prolific powers of nature and the industry of man soon restore what had been lost, and the face of the earth no longer shows traces of the deluge that had overwhelmed it.

* "*Les Inondations en France depuis le VIe siècle jusqu'à nos jours.* 6 vols. 8vo. Paris, 1858–'64. See a very able review of this learned and important work by Prof. Messedaglia, read before the Academy of Agriculture at Verona in 1864."

† "Alfred Maury has, nevertheless, collected, in his erudite and able work *Les Forêts de la Gaule et de l'ancienne France*, Paris, 1867, an immense amount of statistical detail on the extent, the distribution, and the destruction of the forests of France, but it still remains true that we can very seldom pronounce on the forestal condition of the upper valley of a particular river at the time of a given inundation in the ancient or the mediæval period."

Inundations have even their compensations. The structures they destroy are replaced by better and more secure erections; and if they sweep off a crop of corn, they not unfrequently leave behind them, as they subside, a fertilizing deposit which enriches the exhausted field for a succession of seasons.* If, then, the too rapid flow of the surface-waters occasioned no other evil than to produce, once in ten years upon the average, an inundation which should destroy the harvest of the low grounds along the rivers, the damage would be too inconsiderable, and of too transitory a character, to warrant the inconveniences and the expense involved in the measures which the most competent judges in many parts of Europe believe the respective governments ought to take to obviate it.

"DESTRUCTIVE ACTION OF TORRENTS.

"But the great, the irreparable, the appalling mischiefs which have already resulted, and which threaten to ensue on a still more extensive scale hereafter, from too rapid superficial drainage, are of a properly geographical, we may almost say geological, character, and consist primarily in erosion, dis-

* "The productiveness of Egypt has been attributed too exclusively to the fertilizing effects of the slime deposited by the inundations of the Nile; for in that climate a liberal supply of water would produce good crops on almost any ordinary sand, while, without water, the richest soil would yield nothing. The sediment deposited annually is but a very small fraction of an inch in thickness. It is alleged that in quantity it would be hardly sufficient for a good top-dressing, and that in quality it is not chemically distinguishable from the soil inches or feet below the surface. But to deny, as some writers have done, that the slime has any fertilizing properties at all, is as great an error as the opposite one of ascribing all the agricultural wealth of Egypt to that single cause of productiveness. Fine soils deposited by water are almost uniformly rich in all climates; those brought down by rivers, carried out into salt-water, and then returned again by the tide, seem to be more permanently fertile than any others. The polders of the Netherland coast are of this character, and the meadows in Lincolnshire, which have been covered with slime by *warping*, as it is called, or admitting water over them at high tide, are remarkably productive.

"Recent analysis is said to have detected in the water of the Nile a quantity of organic matter—derived mainly, no doubt, from the decayed vegetation it bears down from its tropical course—sufficiently large to furnish an important supply of fertilizing ingredients to the soil.

"It is computed that the Durance—a river fed chiefly by torrents of great erosive power—carries down annually solid material enough to cover 272,000 acres of soil with a deposit of two fifths of an inch in thickness, and that this deposit contains, in the combination most favorable to vegetation, more azote than 110,000 tons of guano, and more carbon than 121,000 acres of woodland would assimilate in a year. Élisée Reclus, *La Terre*, vol. I, p. 467. On the chemical composition, quantity, and value of the solid matter transported by river, see Hervé Mangon, *Sur l'Emploi des Eaux dans les Irrigations*, 8vo. Paris, 1869, pp. 132 *et seq.* Duponchel, *Traité d'Hydraulique et de Géologie Agricoles*. Paris, 1868, chap. I, XII, and XIII."

placement, and transportation of the superficial strata, vegetable and mineral—of the integuments—so to speak, with which nature has clothed the skeleton frame-work of the globe. It is difficult to convey by description an idea of the desolation of the regions most exposed to the ravages of torrent and of flood; and the thousands who, in these days of swift travel, are whirled by steam near or even through the theatres of these calamities, have but rare and imperfect opportunities of observing the destructive causes in action. Still more rarely can they compare the past with the actual condition of the provinces in question, and trace the progress of their conversion from forest-crowned hills, luxuriant pasture grounds, and abundant cornfields and vineyards well watered by springs and fertilizing rivulets, to bald mountain ridges, rocky declivities, and steep earth-banks furrowed by deep ravines with beds now dry, now filled by torrents of fluid mud and gravel hurrying down to spread themselves over the plain, and dooming to everlasting barrenness the once productive fields. In surveying such scenes, it is difficult to resist the impression that nature pronounced a primal curse of perpetual sterility and desolation upon these sublime but fearful wastes, difficult to believe that they were once, and but for the folly of man might still be, blessed with all the natural advantages which Providence has bestowed upon the most favored climes. But the historical evidence is conclusive as to the destructive changes occasioned by the agency of man upon the flanks of the Alps, the Apennines, the Pyrenees, and other mountain ranges in Central and Southern Europe, and the progress of physical deterioration has been so rapid that, in some localities, a single generation has witnessed the beginning and the end of the melancholy revolution.

"I have stated, in a general way, the nature of the evils in question, and of the processes by which they are produced; but I shall make their precise character and magnitude better understood by presenting some descriptive and statistical details of facts of actual occurrence. I select for this purpose the southeastern portion of France, not because that territory has suffered more severely than some others, but because its deterioration is comparatively recent, and has been watched and described by very competent and trustworthy observers, whose reports are more easily accessible than those published in other countries.*

"The provinces of Dauphiny and Provence comprise a territory of fourteen or fifteen thousand square miles, bounded northwest by the Isere, northeast and east by the Alps, south by the Mediterranean, west by the Rhone, and extending from 42° to about 45° of north latitude. The surface is generally hilly and even mountainous, and several of the peaks in Dauphiny rise above the limit of perpetual snow. Except upon the mountain ridges, the climate, as compared with that of the United States in the same latitude, is extremely mild. Little snow falls, except upon the higher mountains, the frosts are light, and the summers long, as might, indeed, be inferred from the vegetation; for in the cultivated districts, the vine and the fig everywhere flourish; the olive thrives as far north as 43½°, and upon the coast grow the orange, the lemon, and the date-palm. The forest trees, too, are of southern type, umbrella pines, various species of evergreen oaks, and many other trees and shrubs of persistent broad-leaved foliage, characterizing the landscape.

"The rapid slope of the mountains naturally exposed these provinces to damage by torrents, and the Romans diminished their injurious effects by erecting, in the beds of ravines, barriers of rocks loosely piled up, which permitted a slow escape of the water, but compelled it to deposit above the dikes the earth and gravel with which it was charged.† At a later

* "Streffleur (*Ueber die Natur und die Wirkungen der Wildbäche*, p. 3) maintains that all the observations and speculations of French authors on the nature of torrents had been anticipated by Austrian writers. In proof of this assertion he refers to the works of Franz von Zallinger, 1778, Von Arretin, 1808, Franz Duile, 1826, all published at Innsbruck, and Hagen's *Beschreibung neuerer Wasserbauwerke* Königsberg, 1826, none of which works are known to me. It is evident, however, that the conclusions of Surell and other French writers whom I cite, are original results of personal investigation, and not borrowed opinions."

† "Whether Palissy was acquainted with this ancient practice, or whether it was one of those original suggestions of which his works are so full, I know not, but in his treatise, *Des Eaux et Fontaines*, he thus recommends it, by way of reply to the objections of 'Théorique,' who had expressed the fear that 'the waters which rush violently down

period the Crusaders brought home from Palestine, with much other knowledge gathered from the wiser Moslems, the art of securing the hillsides and making them productive by terracing and irrigation. The forests which covered the mountains secured an abundant flow of springs, and the process of clearing the soil went on so slowly that, for centuries, neither the want of timber and fuel, nor the other evils about to be depicted, were seriously felt. Indeed, throughout the Middle Ages, these provinces were well wooded, and famous for the fertility and abundance, not only of the low grounds, but of the hills.

"Such was the state of things at the close of the fifteenth century. The statistics of the seventeenth show that while there had been an increase of prosperity and population in Lower Provence, as well as in the correspondingly situated parts of the other two provinces I have mentioned, there was an alarming decrease both in the wealth and in the population of Upper Provence and Dauphiny, although, by the clearing of the forests, a great extent of plough-land and pasturage had been added to the soil before reduced to cultivation. It was found, in fact, that the augmented violence of the torrents had swept away, or buried in sand and gravel, more land than had been reclaimed by clearing; and the taxes computed by fires or habitations underwent several successive reductions in consequence of the gradual abandonment of the wasted soil by its starving occupants. The growth of the large towns on and near the Rhone and the coast, their advance in commerce and industry, and the consequently enlarged demand for agricultural products, ought naturally to have increased the rural population and the value of their lands; but the physical decay of the uplands was such that considerable tracts were deserted altogether, and in Upper Provence, the fires which in 1471

from the heights of the mountain would bring with them much earth, sand, and other things,' and thus spoil the artificial fountain that 'Practique' was teaching him to make: 'And for hindrance of the mischiefs of great waters which may be gathered in few hours by great storms, when thou shalt have made ready thy parterre to receive the water, thou must lay great stones athwart the deep channels which lead to thy parterre. And so the force of the rushing currents shall be deadened, and thy water shall flow peacefully into his cisterns.'—*Œuvres Complètes*, p. 173."

counted 897, were reduced to 747 in 1699, to 728 in 1733, and to 635 in 1776.*

"Surell—whose admirable work, *Étude sur les Torrents des Hautes Alpes*, first published in 1841,† presents a most appalling picture of the desolations of the torrent, and, at the same time, the most careful studies of the history and essential character of this great evil—in speaking of the valley of Dévoluy, on page 152, says: 'Everything concurs to show that it was anciently wooded. In its peat-bogs are found buried trunks of trees, monuments of its former vegetation. In the frame-work of old houses, one sees enormous timber, which is no longer to be found in the district. Many localities, now completely bare, still retain the name of "wood," and one of them is called, in old deeds, *Comba nigra* [Black forest or dell], on account of its dense woods. These and many other proofs confirm the local traditions which are unanimous on this point.

"'There, as everywhere in the Upper Alps, the clearings began on the flanks of the mountains, and were gradually extended into the valleys and then to the highest accessible peaks. Then followed the Revolution, and caused the destruction of the remainder of the trees which had thus far escaped the woodman's axe.'

"In a note to this passage the writer says: 'Several persons have told me that they had lost flocks of sheep, by straying, in the forests of Mont Auroux, which covered the flanks of the mountain from La Cluse to Agnères. These declivities are now as bare as the palm of the hand.'

"The ground upon the steep mountains being once bared of trees, and the underwood killed by the grazing of horned cattle, sheep, and goats, every depression becomes a watercourse. 'Every storm,' says Surell, page 153, 'gives rise to a

* "These facts I take from the *La Provence au point de vue des Bois, des Torrents et des nondations*, of Charles de Ribbe, one of the highest authorities."

† "A second edition of this work, with an additional volume of great value by Ernest Cézanne, was published at Paris, in two 8vo volumes, in 1871–'72."

new torrent.* Examples of such are shown, which, though not yet three years old, have laid waste the finest fields of their valleys, and whole villages have narrowly escaped being swept into ravines formed in the course of a few hours. Sometimes the flood pours in a sheet over the surface, without ravine or even bed, and ruins extensive grounds, which are abandoned forever.'

"I cannot follow Surell in his description and classification of torrents, and I must refer the reader to his instructive work for a full exposition of the theory of the subject. In order, however, to show what a concentration of destructive energies may be effected by felling the woods that clothe and support the sides of mountain abysses, I cite his description of a valley descending from the Col Isoard, which he calls a complete type of a basin of reception,' that is, a gorge which serves as a common point of accumulation and discharge for the waters of several lateral torrents. 'The aspect of the monstrous channel,' says he, 'is frightful. Within a distance of less than two English miles, more than sixty torrents hurl into the depths of the gorge the débris torn from its two flanks. The smallest of these secondary torrents, if transferred to a fertile valley, would be enough to ruin it.'

"The eminent political economist Blanqui, in a memoir read before the Academy of Moral and Political Science on the 25th of November, 1843, thus expresses himself: 'Important as are the causes of impoverishment already described, they are not to be compared to the consequences which have followed from the two inveterate evils of the Alpine provinces of France, the extension of clearing and the ravages of torrents. . . . The most important result of this destruction is this: that the agricultural capital, or rather the ground itself— which, in a rapidly increasing degree, is daily swept away by

* "No attentive observer can frequent the southern flank of the Piedmontese Alps or the French province of Dauphiny, for half a dozen years, without witnessing with his own eyes the formation and increase of new torrents. I can bear personal testimony to the conversion of more than one grassy slope into the bed of a furious torrent by baring the hills above of their woods."

the waters—is totally lost. Signs of unparalleled destitution are visible in all the mountain zone, and the solitudes of those districts are assuming an indescribable character of sterility and desolation. The gradual destruction of the woods has, in a thousand localities, annihilated at once the springs and the fuel. Between Grenoble and Briançon, in the valley of the Romanche, many villages are so destitute of wood that they are reduced to the necessity of baking their bread with sun-dried cow-dung, and even this they can afford to do but once a year.

"'Whoever has visited the valley of Barcelonette, those of Embrun, and of Verdun, and that Arabia Petræa of the department of the Upper Alps, called Dévoluy, knows that there is no time to lose—that in fifty years from this date France will be separated from Savoy, as Egypt from Syria, by a desert.'*

"It deserves to be specially noticed that the district here referred to, though now among the most hopelessly waste in France, was very productive even down to so late a period as the commencement of the French Revolution. Arthur Young, writing in 1789, says: 'About Barcelonette and in the highest parts of the mountains, the hill-pastures feed a million of sheep, besides large herds of other cattle;' and he adds: 'With such a soil and in such a climate, we are not to suppose a country barren because it is mountainous. The valleys I have visited are, in general, beautiful.'† He ascribes the same character to the provinces of Dauphiny, Provence, and Auvergne, and, though he visited, with the eye of an attentive and practiced observer, many of the scenes since blasted with the wild desolation described by Blanqui, the Durance and a part of the course of the Loire are the only streams he

* "Ladoucette says the peasant of Dévoluy 'often goes a distance of five hours over rocks and precipices for a single [man's] load of wood;' and he remarks on another page, that 'the justice of peace of that canton had, in the course of forty-three years, but once heard the voice of the nightingale.'—*Histoire, etc., des Hautes Alpes*, pp. 220, 434."

† "The valley of Embrun, now almost completely devastated, was once remarkable for its fertility. In 1806, Héricart de Thury said of it: 'In this magnificent valley nature had been prodigal of her gifts. Its inhabitants have blindly reveled in her favors, and fallen asleep in the midst of her profusion.'—Becquerel, *Des Climats*, etc., p. 314."

mentions as inflicting serious injury by their floods. The ravages of the torrents had, indeed, as we have seen, commenced earlier in some other localities, but we are authorized to infer that they were, in Young's time, too limited in range, and relatively too insignificant, to require notice in a general view of the provinces where they have now ruined so large a proportion of the soil.

"But I resume my citations.

"'I do not exaggerate,' says Blanqui. 'When I shall have finished my description and designated localities by their names, there will rise, I am sure, more than one voice from the spots themselves, to attest the rigorous exactness of this picture of their wretchedness. I have never seen its equal even in the Kabyle villages of the province of Constantine; for there you can travel on horseback, and you find grass in the spring, whereas in more than fifty communes in the Alps there is absolutely nothing.

"'The clear, brilliant, Alpine sky of Embrun, of Gap, of Barcelonette, and of Digne, which for months is without a cloud, produces droughts interrupted only by diluvial rains like those of the tropics. The abuse of the right of pasturage and the felling of the woods have stripped the soil of all its grass and all its trees, and the scorching sun bakes it to the consistence of porphyry. When moistened by the rain, as it has neither support nor cohesion, it rolls down to the valleys, sometimes in floods resembling black, yellow, or reddish lava, sometimes in streams of pebbles, and even huge blocks of stone, which pour down with a frightful roar, and in their swift course exhibit the most convulsive movements. If you overlook from an eminence one of these landscapes furrowed with so many ravines, it presents only images of desolation and of death. Vast deposits of flinty pebbles, many feet in thickness, which have rolled down and spread far over the plain, surround large trees, bury even their tops, and rise above them, leaving to the husbandman no longer a ray of hope. One can imagine no sadder spectacle than the deep fissures in the flanks of the mountains, which seem to have burst forth in eruption to cover the plains with their ruins. These gorges, under the influence of the sun which cracks and shivers to fragments the very rocks, and of the rain which sweeps them down, penetrate deeper and deeper into the heart of the mountain, while the beds of the torrents issuing from them are sometimes raised several feet in a single year, by the debris, so that they reach the level of the bridges, which, of course, are then carried off. The torrent-beds are recognized at a great distance, as they issue from the mountains, and they spread themselves over the low grounds, in fan-shaped expansions, like a mantle of stone, sometimes ten thousand feet wide, rising high at the centre, and curving toward the circumference till their lower edges meet the plain.

"'Such is their aspect in dry weather. But no tongue can give an adequate description of their devastations in one of those sudden floods which resemble, in almost none of their phenomena, the action of ordinary river-water. They are now no longer overflowing brooks, but real seas, tumbling down in cataracts, and rolling before them blocks of stone, which are hurled forwards by the shock of the waves like balls shot out by the explosion of gunpowder. Sometimes ridges of pebbles are driven down when the transporting torrent does not rise high enough to show itself, and then the movement is accompanied with a roar louder than the crash of thunder. A furious wind precedes the rushing water and announces its approach. Then comes a violent eruption, followed by a flow of muddy waves, and after a few hours all returns to the dreary silence which at periods of rest marks these abodes of desolation.*

* "These explosive gushes of mud and rock appear to be occasioned by the caving in of large masses of earth from the banks of the torrent, which dam up the stream and check its flow until it has acquired volume enough to burst the barrier and carry all before it. In 1827, such a sudden eruption of a torrent, after the current had appeared to have ceased, swept off forty-two houses and drowned twenty-eight persons in the village of Goncelin, near Grenoble, and buried with rubbish a great part of the remainder of the village.

"The French traveler, D'Abbadie, relates precisely similar occurrences as not unfrequent in the mountains of Abyssinia.—Surell, *Études, etc.*, 2d edition, pp. 224, 295."

"'The elements of destruction are increasing in violence. The devastation advances in geometrical progression as the higher slopes are bared of their wood, and "the ruin from above," to use the words of a peasant, "helps to hasten the desolation below."

"'The Alps of Provence present a terrible aspect. In the more equable climate of Northern France, one can form no conception of those parched mountain gorges where not even a bush can be found to shelter a bird, where, at most, the wanderer sees in summer here and there a withered lavender, where all the springs are dried up, and where a dead silence, hardly broken by even the hum of an insect, prevails. But if a storm bursts forth, masses of water suddenly shoot from the mountain heights into the shattered gulfs, waste without irrigating, deluge without refreshing the soil they overflow in their swift descent, and leave it even more seared than it was from want of moisture. Man at last retires from the fearful desert, and I have, the present season, found not a living soul in districts where I remember to have enjoyed hospitality thirty years ago.'

"In 1853, ten years after the date of Blanqui's memoir, M. de Bonville, prefect of the lower Alps, addressed to the government a report in which the following passages occur:

"'It is certain that the productive mould of the Alps, swept off by the increasing violence of that curse of the mountains, the torrents, is daily diminishing with fearful rapidity. All our Alps are wholly, or in large proportion, bared of wood. Their soil, scorched by the sun of Provence, cut up by the hoofs of the sheep, which, not finding on the surface the grass they require for their sustenance, gnaw and scratch the ground in search of roots to satisfy their hunger, is periodically washed and carried off by melting snows and summer storms.

"'I will not dwell on the effects of the torrents. For sixty years they have been too often depicted to require to be further discussed, but it is important to show that their ravages are daily extending the range of devastation. The bed of the Durance, which now in some places exceeds a mile and a quarter in width, and, at ordinary times, has a current of water less than eleven yards wide, shows something of the extent of the damage.* Where, ten years ago, there were still woods and cultivated grounds to be seen, there is now but a vast torrent; there is not one of our mountains which has not at least one torrent, and new ones are daily forming.

"'An indirect proof of the diminution of the soil is to be found in the depopulation of the country. In 1852 I reported to the General Council that, according to the census of that year, the population of the department of the Lower Alps had fallen off no less than 5,000 souls in the five years between 1846 and 1851.

"'Unless prompt and energetic measures are taken, it is easy to fix the epoch when the French Alps will be but a desert. The interval between 1851 and 1856 will show a further decrease of population. In 1862 the ministry will announce a continued and progressive reduction in the number of acres devoted to agriculture; every year will aggravate the evil, and in half a century France will count more ruins, and a department the less.'

"Time has verified the predictions of De Bonville. The later census returns show a progressive diminution in the population of the departments of the Lower Alps, the Isère, Drome, Ariège, the Upper and the Lower Pyrenees, Lozère, and Ardennes, Doubs, the Vosges, and, in short, in all the provinces formerly remarkable for their forests. This diminution is not to be ascribed to a passion for foreign emigration, as in Ireland, and in parts of Germany and of Italy; it is simply a transfer of population from one part of the empire to another, from soils which human folly has rendered uninhabitable, by ruthlessly depriving them of their natural advantages and securities, to provinces where the face of the

* "In the days of the Roman Empire the Durance was a navigable, or at least a boatable, river, with a commerce so important that the boatmen upon it formed a distinct corporation.—Ladoucette, *Historie, etc., des Hautes Alpes*, p. 354.

"Even as early as 1789 the Durance was computed to have already covered with gravel and pebbles not less than 130,000 acres, 'which, but for its inundations, would have been the finest land in the province.'—Arthur Young, *Travels in France*, vol. 1, ch. 1."

earth was so formed by nature as to need no such safeguards, and where, consequently, she preserves her outlines in spite of the wasteful improvidence of man.*

"GENERAL FUNCTIONS OF FORESTS.

"In the preceding pages we have seen that the electrical and chemical action of the forest, though obscure, exercises probably a beneficial, certainly not an injurious, influence on the composition and condition of the atmosphere; that it serves as a protection against the diffusion of miasmatic exhalations and malarious poisons; that it performs a most important function as a mechanical shelter from blasting winds to grounds and crops in the lee of it; that, as a conductor of heat, it tends to equalize the temperature of the earth and the air; that its dead products form a mantle over the surface, which protects the earth from excessive heat and cold; that the evaporation from the leaves of living trees, while it cools the air around them, diffuses through the atmosphere a medium which resists the escape of warmth from the earth by radiation, and hence that its general effect is to equilibrate caloric influences and moderate extremes of temperature.

"We have seen, further, that the forest is equally useful as a regulator of terrestrial and of atmospheric humidity, preventing by its shade the drying up of the surface by parching winds and the scorching rays of the sun, intercepting a part of the precipitation, and pouring out a vast quantity of aqueous vapor into the atmosphere; that if it does not increase the amount of rain, it tends to equalize its distribution both in time and in place; that it preserves a hygrometric equilibrium in the superior strata of the earth's surface; that it maintains and regulates the flow of springs and rivulets; that it checks

* "Between 1851 and 1856 the population of Languedoc and Provence had increased by 101,000 souls. The augmentation, however, was wholly in the provinces of the plains, where all the principal cities are found. In these provinces the increase was 204,000, while in the mountain provinces there was a diminution of 103,000. The reduction of the area of arable land is perhaps even more striking. In 1842 the department of the Lower Alps possessed 99,000 hectares, or nearly 245,000 acres, of cultivated soil. In 1852 it had but 74,000 hectares. In other words, in ten years 25,000 hectares, or 61,000 acres, had been washed away, or rendered worthless for cultivation, by torrents and the abuses of pasturage.—Clavé, *Études*, pp. 66, 67."

the superficial discharge of the waters of precipitation, and consequently tends to prevent the sudden rise of rivers, the violence of floods, the formation of destructive torrents, and the abrasion of the surface by the action of running water; that it impedes the fall of avalanches and of rocks, and destructive slides of the superficial strata of mountains; that it is a safeguard against the breeding of locusts, and finally that it furnishes nutriment and shelter to many tribes of animal and of vegetable life which, if not necessary to man's existence, are conducive to his rational enjoyment. In fine, in well-wooded regions, and in inhabited countries where a due proportion of soil is devoted to the growth of judiciously distributed forests, natural destructive tendencies of all sorts are arrested or compensated, and man, bird, beast, fish, and vegetable alike find a constant uniformity of condition most favorable to the regular and harmonious coexistence of them all.

"GENERAL CONSEQUENCES OF THE DESTRUCTION OF THE FOREST.

"With the extirpation of the forest, all is changed. At one season, the earth parts with its warmth by radiation to an open sky—receives, at another, an immoderate heat from the unobstructed rays of the sun. Hence the climate becomes excessive, and the soil is alternately parched by the fervors of summer, and seared by the rigors of winter. Bleak winds sweep unresisted over its surface, drift away the snow that sheltered it from the frost, and dry up its scanty moisture. The precipitation becomes as irregular as the temperature; the melting snows and vernal rains, no longer absorbed by a loose and bibulous vegetable mould, rush over the frozen surface, and pour down the valleys seawards, instead of filling a retentive bed of absorbent earth, and storing up a supply of moisture to feed perennial springs. The soil is bared of its covering of leaves, broken and loosened by the plough, deprived of the fibrous rootlets which held it together, dried and pulverized by sun and wind, and at last exhausted by new combinations. The face of the earth is no longer a sponge, but a dust-heap, and the floods which the waters of the sky pour over it hurry swiftly along its slopes, carrying in suspension vast quantities of earthy particles which increase the abrading power and mechanical force of the current, and, augmented by the sand and gravel of falling banks, fill the beds of the streams, divert them into new channels, and obstruct their outlets. The rivulets, wanting their former regularity of supply and deprived of the protecting shade of the woods, are heated, evaporated, and thus reduced in their summer currents, but swollen to raging torrents in autumn and in spring. From these causes, there is a constant degradation of the uplands, and a consequent elevation of the beds of water-courses and of lakes by the deposition of the mineral and vegetable matter carried down by the waters. The channels of great rivers become unnavigable, their estuaries are choked up, and harbors which once sheltered large navies are shoaled by dangerous sand-bars. The earth, stripped of its vegetable glebe, grows less and less productive, and, consequently, less able to protect itself by weaving a new network of roots to bind its particles together, a new carpeting of turf to shield it from wind and sun and scouring rain. Gradually it becomes altogether barren. The washing of the soil from the mountains leaves bare ridges of sterile rock, and the rich organic mould which covered them, now swept down into the dank low grounds, promotes a luxuriance of aquatic vegetation that breeds fever, and more insidious forms of mortal disease, by its decay, and thus the earth is rendered no longer fit for the habitation of man.*

"To the general truth of this sad picture there are many exceptions, even in countries of excessive climates. Some of these are due to favorable conditions of surface, of geological structure, and of the distribution of rain; in many others, the evil consequences of man's improvidence have not yet been

* "Almost every narrative of travel in those countries which were the earliest seats of civilization, contains evidence of the truth of these general statements, and this evidence is presented with more or less detail in most of the special works on the forest which I have occasion to cite. I may refer particularly to Hohenstein, *Der Wald*, 1860, as full of important facts on this subject. See also Caimi, *Cenni sulla Importanza dei Boschi*, for some statistics, not readily found elsewhere, on this and other topics connected with the forest."

experienced, only because a sufficient time has not elapsed, since the felling of the forest, to allow them to develop themselves. But the vengeance of nature for the violation of her harmonies, though slow, is sure, and the gradual deterioration of soil and climate in such exceptional regions is as certain to result from the destruction of the woods as is any natural effect to follow its cause.

"DUE PROPORTION OF WOODLAND.

"The proportion of woodland that ought to be permanently maintained for its geographical and atmospheric influences varies according to the character of soil, surface, and climate. In countries with a humid sky, or moderately undulating surface and an equable temperature, a small extent of forest, enough to serve as a mechanical screen against the action of the wind in localities where such protection is needed, suffices. But most of the territory occupied by civilized man is exposed, by the character of its surface and its climate, to a physical degradation which cannot be averted except by devoting a large amount of soil to the growth of the woods.

"From an economical point of view, the question of the due proportion of forest is not less complicated or less important than in its purely physical aspects. Of all the raw materials which nature supplies for elaboration by human art, wood is undoubtedly the most useful, and at the same time the most indispensable to social progress.*

* "In an imaginary dialogue in the *Recepte Véritable*, the author, Palissy, having expressed his indignation at the folly of men in destroying the woods, his interlocutor defends the policy of felling them, by citing the example of 'divers bishops, cardinals, priors, abbots, monkeries, and chapters, which, by cutting their woods, have made three profits,' the sale of the timber, the rent of the ground, and the 'good portion' they received of the grain grown by the peasants upon it. To this argument Palissy replies: 'I cannot enough detest this thing, and I call it not an error, but a curse and a calamity to all France; for when forests shall be cut, all arts shall cease, and they which practice them shall be driven out to eat grass with Nebuchadnezzar and the beasts of the field. I have divers times thought to set down in writing the arts which shall perish when there shall be no more wood; but when I had written down a great number, I did perceive that there could be no end of my writing, and having diligently considered, I found there was not any which could be followed without wood.' . . . 'And truly I could well allege to thee a thousand reasons, but 'tis so cheap a philosophy, that the very chamber-wenches, if they do but think, may see that without wood, it is not possible to exercise any manner of human art or cunning.'—*Œuvres de* Bernard Palissy. Paris, 1844, p. 89."

"The demand for wood, and of course the quantity of forest required to furnish it, depend upon the supply of fuel from other sources, such as peat and coal, upon the extent to which stone, brick, or metal can advantageously be substituted for wood in building, upon the development of arts and industries employing wood and other forest products as materials, and upon the cost of obtaining them from other countries, or upon their commercial value as articles of export.

"Upon the whole, taking civilized Europe and America together, it is probable that from twenty to twenty-five per cent. of well-wooded surface is indispensable for the maintenance of normal physical conditions, and for the supply of materials so essential to every branch of human industry and every form of social life as those which compose the harvest of the woods.

"There is probably no country—there are few large farms even—where at least one fourth of the soil is not either unfit for agricultural use, or so unproductive that, as pasture or as ploughland, it yields less pecuniary return than a thrifty wood. Every prairie has its sloughs where willows and poplars would find a fitting soil, every Eastern farm its rocky nooks and its barren hillsides suited to the growth of some species from our rich forest flora, and everywhere belts of trees might advantageously be planted along the road-sides and the boundaries and dividing fences. In most cases, it will be found that trees may be made to grow well where cultivated crops will not repay the outlay of tillage, and it is a very plain dictate of sound economy, that if trees produce a better profit than the same ground would return if devoted to grass or grain, the wood should be substituted for the field.

"WOODLAND IN EUROPEAN COUNTRIES.

"In 1862, Rentzsch calculated the proportions of woodland in different European countries as follows:*

Norway	66	per cent.
Sweden	60	"
Russia	30.90	"

*"*Der Wald*, pp. 123, 124."

Germany	26.58 per cent.
Belgium	18.52 "
France	16.79 "
Switzerland	15 "
Sardinia	12.29 "
Neapolitan States	9.43 "
Holland	7.10 "
Spain	5.52 "
Denmark	5.50 "
Great Britain	5 "
Portugal	4.40 "

"The large proportion of woodland in Norway and Sweden is in a great measure to be ascribed to the mountainous character of the surface, which renders the construction of roads difficult and expensive, and hence the forests are comparatively inaccessible, and transportation is too costly to tempt the inhabitants to sacrifice their woods for the sake of supplying distant markets.

"The industries which employ wood as a material have only lately been much developed in these countries, and though the climate requires the consumption of much wood as a fuel, the population is not numerous enough to create, for this purpose, a demand exceeding the annually produced supply, or to need any great extension of cleared ground for agricultural purposes. Besides this, in many places peat is generally employed as domestic fuel. Hence, though Norway has long exported a considerable quantity of lumber,* and the iron and copper works of Sweden consume charcoal very largely, the forests have not diminished rapidly enough to produce very sensible climatic or even economical evils.

"At the opposite end of the scale we find Holland, Denmark, Great Britain, Spain, and Portugal. In the three first named countries a cold and humid climate renders the almost constant maintenance of domestic fires a necessity, while in Great Britain especially the demand of the various industries which depend on wood as a material, or on mechanical power

* "Railway ties, or, as they are called in England, *sleepers*, are largely exported from Norway to India, and sold at Calcutta at a lower price than timber of equal quality can be obtained from the native woods.—*Reports on Forest Conservancy*, vol. I, pt. II, p. 1533.

"From 1861 to 1870 Norway exported annually, on the average, more than 60,000,000 cubic feet of lumber.—Wulfsberg, *Norges Velstandskilder*. Christiania, 1872."

derived from heat, are very great. Coal and peat serve as a combustible instead of wood in them all, and England imports an immense quantity of timber from her foreign possessions. Fortunately, the character of soil, surface, and climate renders the forest of less importance as a geographical agent in these northern regions than in Spain and Portugal, where all physical conditions concur to make a large extent of forest an almost indispensable means of industrial progress and social advancement.

"Rentzsch, in fact, ascribes the political decadence of Spain almost wholly to the destruction of the forest. 'Spain,' observes he, 'seemed destined by her position to hold dominion over the world, and this in fact she once possessed. But she has lost her political ascendency, because, during the feeble administration of the successors of Philip II, her exhausted treasury could not furnish the means of creating new fleets, the destruction of the woods having raised the price of timber above the means of the State.'* On the other hand, the same writer argues that the wealth and prosperity of modern England are in great part due to the supply of lumber, as well as of other material for ship-building, which she imports from her colonies and other countries with which she maintains commercial relations.

"FORESTS OF GREAT BRITAIN.

"The proportion of forest is very small in Great Britain, where, as I have said, on the one hand, a prodigious industrial activity requires a vast supply of ligneous material, but where,

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* "*Der Wald*, p. 63. Antonio Ponz (*Viage de España* I, prólogo, p. LXIII), says: 'Nor would this be so great an evil, were not some of them declaimers against *trees*, thereby proclaiming themselves, in some sort, enemies of the works of God, who gave us the leafy abode of Paradise to dwell in, where we should be even now sojourning, but for the first sin, which expelled us from it.'

"I do not know at what period the two Castiles were bared of their woods, but the Spaniard's proverbial 'hatred of a tree' is of long standing. Herrera combats this foolish prejudice; and Ponz, in the prologue to the ninth volume of his journey, says that many carried it so far as wantonly to destroy the shade and ornamental trees planted by the municipal authorities. 'Trees,' they contended, and still believe, 'breed birds, and birds eat up the grain.' Our author argues against the supposition of the 'breeding of birds by trees,' which, he says, is as absurd as to believe that an elm tree can yield pears; and he charitably suggests that the expression is, perhaps, a *manière de dire*, a popular phrase, signifying simply that trees harbor birds."

on the other, the abundance of coal, which furnishes a sufficiency of fuel, the facility of importation of timber from abroad, and the conditions of climate and surface combine to reduce the necessary quantity of woodland to its lowest expression.

"With the exception of Russia, Denmark, and parts of Germany, no European countries can so well dispense with the forests, in their capacity of conservative influences, as England and Ireland. Their insular position and latitude secure an abundance of atmospheric moisture; the general inclination of surface is not such as to expose it to special injury from torrents, and it is probable that the most important climatic action exercised by the forest in these portions of the British empire, is in its character of a mechanical screen against the effects of wind. The due proportion of woodland in England and Ireland is, therefore, a question not of geographical, but almost purely of economical, expediency, to be decided by the comparative direct pecuniary return from forest growth, pasturage, and ploughland.

"Contrivances for economizing fuel came later into use in the British Islands than on the Continent. Before the introduction of a system of drainage, the soil, like the sky, was, in general, charged with humidity; its natural condition was unfavorable for the construction and maintenance of substantial common roads, and the transportation of so heavy a material as coal, by land, from the remote counties where alone it was mined in the Middle Ages, was costly and difficult. For all these reasons, the consumption of wood was large, and apprehensions of the exhaustion of the forests were excited at an early period. Legislation there, as elsewhere, proved ineffectual to protect them, and many authors of the sixteenth century express fears of serious evils from the wasteful economy of the people in this respect.† * * * *

"Evelyn's 'Silva,' the first edition of which appeared in 1664, rendered an extremely important service to the cause of the woods, and there is no doubt that the ornamental plantations in which England far surpasses all other countries, are,

† A foot-note of the author is omitted here.

in some measure, the fruit of Evelyn's enthusiasm. In England, however, arboriculture, the planting and nursing of single trees, has, until comparatively recent times, been better understood than sylviculture, the sowing and training of the forest. But this latter branch of rural improvement now receives great attention from private individuals, though, so far as I know, not from the National Government, except in the East Indian provinces, where the forestal department has assumed great importance.*

"In fact, England is, I believe, the only European country where private enterprise has pursued sylviculture on a really great scale, though admirable examples have been set in many others. In England the law of primogeniture, and other institutions and national customs which tend to keep large estates long undivided and in the same line of inheritance, the wealth of the landholders, the special adaptation of the climate to the growth of forest trees, and the difficulty of finding safe and profitable investments of capital, combine to afford encouragements for the plantation of forests, which scarcely exist elsewhere in the same degree.

"In Scotland, where the country is for the most part broken and mountainous, the general destruction of the forests has been attended with very serious evils, and it is in Scotland that many of the most extensive British forest plantations have now been formed. But although the inclination of surface in Scotland is rapid, the geological constitution of the soil is not of a character to promote such destructive degradation by

* "The improvidence of the population under the native and early foreign governments has produced great devastations in the forests of the British East Indian provinces, and the demands of the railways for fuel and timber have greatly augmented the consumption of lumber, and of course contributed to the destruction of the woods. The forests of British India are now, and for several years have been, under the control of an efficient governmental organization, with great advantage both to the government and to the general private interests of the people.

"The official Reports on Forest Conservancy from May, 1862, to August, 1871, in 4 vols. folio, contain much statistical and practical information on all subjects connected with the administration of the forest.

"Many laws for the protection of the forest, as a cover for game, and for the preservation of ship-timber, were enacted in England before the seventeenth century. The Statutes I Eliz. c. XV, XIII Eliz. c. V, and XXVII Eliz. c. XIX, which have sometimes been understood as designed to discourage the manufacture of iron, were obviously intended to prevent the destruction of large and valuable timber, useful in ordinary and naval architecture, by burning it for charcoal. The injury to the forges was accidental, not the purpose of the laws."

running water as in Southern France, and it has not to contend with the parching droughts by which the devastations of the torrents are rendered more injurious in those provinces.

"It is difficult to understand how either law or public opinion, in a country occupied by a dense and intelligent population, and, comparatively speaking, with an infertile soil, can tolerate the continued withdrawal of a great portion of the territory from the cultivation of trees and from other kinds of rural economy, merely to allow wealthy individuals to amuse themselves with field sports. In Scotland, 2,000,000 acres, as well suited to the growth of forests and for pasture as is the soil generally, are withheld from agriculture, that they may be given up to herds of deer protected by the game laws. A single nobleman, for example, thus appropriates for his own pleasures not less than 100,000 acres.* In this way one tenth of all the land of Scotland is rendered valueless in an economical point of view—for the returns from the sale of the venison and other game scarcely suffice to pay the game-keepers and other incidental expenses—and in these so-called *forests* there grows neither building timber nor fire-wood worth the cutting, as the animals destroy the young shoots.

"FORESTS OF FRANCE.

"The preservation of the woods was one of the wise measures recommended to France by Sully, in the time of Henry IV, but the advice was little heeded, and the destruction of the forests went on with such alarming rapidity, that, two generations later, Colbert uttered the prediction: 'France will perish for want of wood.' Still, the extent of wooded soil was very great, and the evils attending its diminution were not so sensibly felt, that either the government or public opinion saw the necessity of authoritative interference, and in 1750 Mirabeau estimated the remaining forests of the kingdom at seventeen millions of hectares [42,000,000 acres]. In 1860 they were reduced to eight millions [19,769,000 acres], or at the rate of 82,000 hectares [202,600 acres] per year. Troy,

* "Robertson, *Our Deer Forests*. London, 1867."

from whose valuable pamphlet, *Étude sur le Reboisement des Montagnes*, I take these statistical details, supposes that Mirabeau's statement may have been an extravagant one, but it still remains certain that the waste has been enormous; for it is known that, in some departments, that of Ariège, for instance, clearing has gone on during the last half century at the rate of three thousand acres a year, and in all parts of the empire trees have been felled faster than they have grown.* The total area of France in Mirabeau's time, excluding Savoy, but including Alsace and Lorraine, was about one hundred and thirty-one millions of acres. The extent of forest supposed by Mirabeau would be about thirty-two per cent. of the whole territory. In a country and a climate where the conservative influences of the forest are so necessary as in France, trees must cover a large surface and be grouped in large masses, in order to discharge to the best advantage the various functions assigned to them by nature. The consumption of wood is rapidly increasing in that empire, and a large part of its territory is mountainous, sterile, and otherwise such in character or situation that it can be more profitably devoted to the growth of wood than to any agricultural use. Hence it is evident that the proportion of forest in 1750, taking even Mirabeau's large estimate, was not very much too great for permanent maintenance, though doubtless the distribution was so unequal that it would have been sound policy to fell the woods and clear land in some provinces, while large forests

* "Among the indirect proofs of the comparatively recent existence of extensive forests in France, may be mentioned the fact that wolves were abundant, not very long since, in parts of the empire where there are now neither wolves nor woods to shelter them. Arthur Young more than once speaks of the 'innumerable multitudes' of these animals which infested France in 1789, and George Sand states, in the *Histoire de ma Vie*, that some years after the restoration of the Bourbons, they chased travelers on horseback in the southern provinces, and literally knocked at the doors of her father-in-law's country seat. Eugénie de Guérin, writing from Rayssac in Languedoc in 1831, speaks of hearing the wolves fighting with dogs in the night under her very windows. *Lettres*, 2d ed., p. 6.

"There seems to have been a tendency to excessive clearing in Central and Western, earlier than in Southeastern, France. Bernard Palissy, in the *Recepte Véritable*, first printed in 1563, thus complains: 'When I consider the value of the least clump of trees, or even of thorns, I much marvel at the great ignorance of men, who, as it seemeth, do nowadays study only to break down, fell, and waste the fair forests which their forefathers did guard so choicely. I would think no evil of them for cutting down the woods, did they but replant again some part of them; but they care nought for the time to come, neither reck they of the great damage they do to their children which shall come after them.'—*Œuvres Complètes de* Bernard Palissy, 1844, p. 88.

should have been planted in others.* During the period in question France neither exported manufactured wood or rough timber, nor derived important collateral advantages of any sort from the destruction of her forests. She is consequently impoverished and crippled to the extent of the difference between what she actually possesses of wooded surface and what she ought to have retained.†

"The force of the various considerations which have been suggested in regard to the importance of the forest has been generally felt in France, and the subject has been amply debated in special treatises, in scientific journals, and by the public press, as well as in the legislative body of that country. Perhaps no one point has been more prominent in the discussions than the influence of the forest in equalizing and regulating the flow of the water of precipitation. Opinion is still somewhat divided on this subject, but the value of the woods as a safeguard against the ravages of torrents is universally acknowledged, and it is hardly disputed that the rise of river-floods is, even if as great, at least less sudden in streams having their sources in well-wooded territory.

"Upon the whole, the conservative action of the woods in regard to torrents and to inundations has been generally recognized by the public of France as a matter of prime importance, and the Government of the empire has made this principle the basis of a special system of legislation for the

* "The view I have taken of this point is confirmed by the careful investigations of Rentzsch, who estimates the proper proportion of woodland to entire surface at twenty-three per cent. for the interior of Germany, and supposes that near the coast, where the air is supplied with humidity by evaporation from the sea, it might safely be reduced to twenty per cent. See Rentzsch's very valuable prize essay, *Der Wald im Haushalt der Natur und der Volkswirths-haft*, cap. VIII.

"The due proportion in France would considerably exceed that for the German States, because France has relatively more surface unfit for any growth but that of wood, because the form and geological character of her mountains expose her territory to much greater injury from torrents, and because at least her southern provinces are more frequently visited both by extreme droughts and by deluging rains."

† "In 1863, France imported lumber to the value of twenty-five and a half millions of dollars, and exported to the amount of six and a half millions of dollars. The annual consumption of France was estimated in 1866 at 212,000,000 cubic feet for building and manufacturing, and 1,588,500,000 for fire-wood and charcoal. The annual product of the forest-soil of France does not exceed 70,000,000 cubic feet of wood fit for industrial use, and 1,300,000,000 cubic feet consumed as fuel. This estimate does not include the product of scattered trees on private grounds, but the consumption is estimated to exceed the production of the forests by the amount of about twenty millions of dollars. It is worth noticing that the timber for building and manufacturing produced in France comes almost wholly from the forests of the state or of the communes.—Jules Clavé, in *Revue des Deux Mondes* for March 1, 1866, p. 207."

protection of existing forests, and for the formation of new. The clearing of woodland, and the organization and functions of a police for its protection, are regulated by a law bearing date June 18th, 1859, and provision was made for promoting the restoration of private woods by a statute adopted on the 28th of July, 1860. The former of these laws passed the legislative body by a vote of 246 against 4, the latter with but a single negative voice. The influence of the Government, in a country where the throne is so potent as in France, would account for a large majority, but when it is considered that both laws, the former especially, interfere very materially with the rights of private domain, the almost entire unanimity with which they were adopted is proof of a very general popular conviction, that the protection and extension of the forests is a measure more likely than any other to arrest the devastations of the torrents and check the violence, if not to prevent the recurrence, of destructive river inundations. The law of July 28th, 1860, appropriated 10,000,000 francs, to be expended, at the rate of 1,000,000 francs per year, in executing or aiding the replanting of woods. It is computed that this appropriation—which, considering the vast importance of the subject, does not seem extravagant for a nation rich enough to be able to expend annually six hundred times that sum in the maintenance of its military establishments in times of peace—will secure the creation of new forest to the extent of about 200,000 acres, or one fourteenth part of the soil, where the restoration of the woods is thought feasible, and, at the same time, specially important as a security against the evils ascribed, in a great measure, to its destruction.*

* "In 1848 the Government of the so-called French Republic sold to the Bank of France 187,000 acres of public forests, and notwithstanding the zeal with which the Imperial Government had pressed the protective legislation of 1860, it introduced into the Legislative Assembly in 1865 a bill for the sale, and consequently destruction, of the forests of the state to the amount of one hundred million francs. The question was much debated in the Assembly, and public opinion manifested itself so energetically against the measure that the ministry felt itself compelled to withdraw it. See the discussions in *L'Aliénation des Forêts de l'État.* Paris, 1865.

"The late Imperial Government sold about 170,000 acres of woodland between 1852 and 1866, both inclusive. The other Governments, since the restoration of the Bourbons in 1814, alienated more than 700,000 acres of the public forests, exclusive of sales between 1836 and 1857, which are not reported.—*Annuaire des Eaux et Forêts*, 1872, p. 9."

"In 1865 the Legislative Assembly passed a bill amendatory of the law of 1860, providing, among other things, for securing the soil in exposed localities by grading, and by promoting the growth of grass and the formation of greensward over the surface. This has proved a most beneficial measure, and its adoption under corresponding conditions in the United States is most highly to be recommended. The leading features of the system are:

"1. Marking out and securing from pasturage and all other encroachments a zone along the banks and around the head of ravines.

"2. Turfing this zone, which in France accomplishes itself, if not spontaneously, at least with little aid from art.

"3. Consolidation of the scarps of the ravines by grading and wattling and establishing barriers, sometimes of solid masonry, but generally of fascines or any other simple materials at hand, across the bed of the stream.

"4. Cutting *banquettes* or narrow terraces along the scarps, and planting rows of small deciduous trees and arborescent shrubs upon them, alternating with belts of grass obtained by turfing with sods or sowing grass-seeds. Planting the banquettes and slopes with bushes, and sowing any other vegetables with tenacious roots, is also earnestly recommended.*

"REMEDIES AGAINST TORRENTS.

"The rural population, which in France is generally hostile to all forest laws, soon acquiesced in the adoption of this system, and its success has far surpassed all expectation. At the end of the year 1868 about 190,000 acres had been planted with trees,† and nearly 7,000 acres well turfed over in the

* "See a description of similar processes recommended and adopted by Mengotti, in his *Idraulica*, vol. II, chap. XVII."

† "Travelers spending the winter at Nice may have a good opportunity of studying the methods of forming and conducting the re-wooding of mountain slopes, under the most unfavorable conditions, by visiting Mont Boron, in the immediate vicinity of that city, and other coast plantations in that province, where great difficulties have been completely overcome by the skill and perseverance of French foresters. See *Les Forêts des Maures*, *Revue des Eaux et Forêts*, January, 1869.

"Still more formidable difficulties have been vanquished in re-wooding Mont Faron near Toulon, and it is hardly hyperbolical to say that this is a case of impossibilities conquered. See *Revue des Eaux et Forêts*, February, 1873.

Department of the Hautes Alpes. Many hundred ravines, several of which had been the channels of formidable torrents, had been secured by barriers, grading and planting, and according to official reports the aspect of the mountains in the Department, wherever these methods were employed, had rapidly changed. The soil had acquired such stability that the violent rains of 1868, so destructive elsewhere, produced no damage in the districts which had been subjected to these operations, and numerous growing torrents which threatened irreparable mischief had been completely extinguished, or at least rendered altogether harmless.*

"Besides the processes directed by the Government of France, various subsidiary measures of an easily and economically practicable character have been suggested. Among them is one which has long been favorably known in our Southern States under the name of *circling*, and the adoption of which in hilly regions in other States is to be strongly recommended.

"It is simply a method of preventing the wash of surface by rains, and at the same time of providing a substitute for irrigation of steep pasture grounds, consisting in little more than in running horizontal furrows along the hillsides, thus converting the scarp of the hills into a succession of small terraces which, when once turfed over, are very permanent. Experience is said to have demonstrated that this simple process at least partially checks the too rapid flow of surface-water into the valleys, and, consequently, in a great measure obviates one of the most prominent causes of inundations, and that it suffices to retain the water of rains, of snows, and of small springs, long enough for the irrigation of the soil, thus increasing its product of herbage in a five-fold proportion.†

"As a further recommendation, it may be observed that this process is an admirable preparation of the ground for

*"For ample details of processes and results, see the second volume of Surell, *Étude sur les Torrents*, Paris, 1872, and a Report by De La Grye, in the *Revue des Eaux et Forêts* for January, 1869."

†"Troy, *Étude sur le Reboisement des Montagnes*, §§ 6, 7, 21."

forest plantations, as young trees planted on the terraces would derive a useful protection from the form of the surface and the coating of turf, and would also find a soil moist enough to secure their growth.

"FORESTS OF ITALY.

"According to the most recent statistics, Italy has 17.64 per cent. of woodland,* a proportion which, considering the character of climate and surface, the great amount of soil which is fit for no other purpose than the growth of trees, and the fact that much of the land classed as forest is either very imperfectly wooded, or covered with groves badly administered, and not in a state of progressive improvement, might advantageously be doubled. Taking Italy as a whole, we may say that she is eminently fitted by climate, soil, and superficial formation, to the growth of a varied and luxuriant arboreal vegetation, and that in the interests of self-protection, the promotion of forestal industry is among the first duties of her people. There are in Western Piedmont valleys where the felling of the woods has produced consequences geographically and economically as disastrous as in Southeastern France, and there are many other districts in the Alps and the Apennines where human improvidence has been almost equally destructive. Some of these regions must be abandoned to absolute desolation, and for others the opportunity of physical restoration is rapidly passing away. But there are still millions of square miles which might profitably be planted with forest trees, and thousands of acres of parched and barren hillside, within sight of almost every Italian provincial capital, which might easily and shortly be re-clothed with verdant woods.†

* "Siemoni, *Manuale d'Arte Forestale*, 2 ediz., Firenze, 1872, p. 542."

† "To one accustomed to the slow vegetation of less favored climes, the rapidity of growth in young plantations in Italy seems almost magical. The trees planted along the new drives and avenues in Florence have attained in three or four years a development which would require at least ten in our Northen States. This, it is true, is a special case, for the trees have been planted and tended with a skill and care which cannot be bestowed upon a forest; but the growth of trees little cared for is still very rapid in Italy. According to Toscanelli, *Economia rurale nella Provincia di Pisa*, p. 8, *note*—one of the most complete, curious, and instructive pictures of rural life which exists in any literature—the white poplar, *Populus alba*, attains in the valley of the Serchio a great height, with a mean diameter of two feet, in twenty years. Selmi states in his *Miasma Palustre*, p. 115,

"The denudation of the Central and Southern Apennines and of the Italian declivity of the Western Alps began at a period of unknown antiquity, but it does not seem to have been carried to a very dangerous length until the foreign conquests and extended commerce of Rome created a greatly increased demand for wood for the construction of ships and for military material.* The Eastern Alps, the Western Apennines, and the Maritime Alps retained their forests much later; but even here the want of wood, and the injury to the plains and the navigation of the rivers by sediment brought down by the torrents, led to legislation for the protection of the forests, by the Republic of Venice, at various periods between the fifteenth and the nineteenth centuries;† by that of Genoa as early at least as the seventeenth; and both these Governments, as well as several others, passed laws requiring the proprietors of mountain lands to replant the woods. These, however, seem to have been little observed, and it is generally true that the present condition of the forest in Italy is much less due to the want of wise legislation for its protection than to the laxity of the Governments in enforcing their laws.

"It is very common in Italy to ascribe to the French occupation under the first Empire all the improvements and all the abuses of recent times, according to the political sympathies of the individual; and the French are often said to have prostrated every forest which has disappeared within this century. But, however this may be, no energetic system of repression or restoration was adopted by any of the Italian States after the downfall of the Empire, and the taxes on forest property in some of them were so burdensome that rural municipalities sometimes proposed to cede their common woods to the Government, without any other compensation than the remission of the taxes imposed on forest lands.‡ Under such circum-

that the linden reaches a diameter of sixteen inches in the same period. The growth of foreign trees is sometimes extremely luxuriant in Italy. Two Atlas cedars, at the well-known villa of Careggi, near Florence, grown from seed sown in 1850, measure twenty inches in diameter, above the swell of the roots, with an estimated height of sixty feet."

*† Two foot-notes of the author are omitted here.

‡ "See the *Politecnico* for the month of May, 1862, p. 234."

stances, woodlands would soon become disafforested, and where facilities of transportation and a good demand for timber have increased the inducements to fell it, as upon the borders of the Mediterranean, the destruction of the forest and all the evils which attend it have gone on at a seriously alarming rate.

"Gallenga gives a striking account of the wanton destruction of the forests in Northern Italy within his personal recollection,* and there are few Italians past middle life whose own memory will not supply similar reminiscences. The clearing of the mountain valleys of the provinces of Bergamo and of Brescia is recent, and Lombardini informs us the felling of the woods in the Valtelline commenced little more than forty years ago.

"Although no country has produced more able writers on the value of the forest and the general consequences of its destruction than Italy, yet the specific geographical importance of the woods, except as a protection against inundations, has not been so clearly recognized in that country as in the States bordering it on the north and west. It is true that the face of nature has been as completely revolutionized by man, and that the action of torrents has created almost as wide and as hopeless devastation in Italy as in France; but in the French Empire the recent desolation produced by clearing the forests is more extensive, has been more suddenly effected, has occurred in less remote and obscure localities, and, therefore, excites a livelier and more general interest than in Italy, where public opinion does not so readily connect the effect with its true cause. Italy, too, from ancient habit, employs little wood in architectural construction; for generations she has maintained no military or commercial marine large enough to require exhaustive quantities of timber,† and the mildness

*"'Far away in the darkest recesses of the mountains a kind of universal conspiracy seems to have been got up among these Alpine people—a destructive mania to hew and sweep down everything that stands on roots.'—*Country Life in Piedmont*, p. 134.

"'There are huge pyramids of mountains now bare and bleak from base to summit, which men still living and still young remember seeing richly mantled with all but primeval forests.'—*Ibid*, p. 135."

†A foot-note of the author is omitted here.

of her climate makes small demands on the woods for fuel. Besides these circumstances, it must be remembered that the sciences of observation did not become knowledges of practical application till after the mischief was already mainly done and even forgotten in Alpine Italy, while its evils were just beginning to be sensibly felt in France when the claims of natural philosophy as a liberal study were first acknowledged in modern Europe. The former political condition of the Italian Peninsula would have effectually prevented the adoption of a general system of forest economy, however clearly the importance of a wise administration of this great public interest might have been understood. The woods which controlled and regulated the flow of the river-sources were very often in one jurisdiction, the plains to be irrigated, or to be inundated by floods and desolated by torrents, in another. Concert of action, on such a subject, between a multitude of jealous petty sovereignties, was obviously impossible, and nothing but the permanent union of all the Italian States under a single government can render practicable the establishment of such arrangements for the conservation and restoration of the forests, and the regulation of the flow of the waters, as are necessary for the full development of the yet unexhausted resources of that fairest of lands, and even for the maintenance of the present condition of its physical geography.

"THE FORESTS OF GERMANY.

"Germany, including a considerable part of the Austrian Empire, from character of surface and climate, and from the attention which has long been paid in all the German States to sylviculture, is in a far better condition in this respect than its more southern neighbors; and though in the Alpine provinces of Bavaria and Austria the same improvidence which marks the rural economy of the corresponding districts of Switzerland, Italy, and France, has produced effects hardly less disastrous,* yet, as a whole, the German States, as Siemoni well observes, must be considered as in this respect the model countries of Europe. Not only is the forest area in general maintained without diminution, but new woods are planted where they are specially needed,† and, though the slow growth of forest trees in those climates reduces the direct pecuniary returns of woodlands to a minimum, the governments wisely persevere in encouraging this industry. The exportation of sawn lumber from Trieste is large, and in fact the Turkish and Egyptian markets are in great part supplied from this source.‡

"FORESTS OF RUSSIA.

"Russia, which we habitually consider as substantially a forest country—which has in fact a large proportion of woodland—is beginning to suffer seriously for want of wood. Jourdier observes: 'Instead of a vast territory with immense forests, which we expect to meet, one sees only scattered groves thinned by the wind or by the axe of the *moujik*, grounds cut

* "As an instance of the scarcity of fuel in some parts of the territory of Bavaria, where, not long since, wood abounded, I may mention the fact that the water of salt springs is, in some instances, conveyed to the distance of sixty miles, in iron pipes, to reach a supply of fuel for boiling it down.

"In France, the juice of the sugar-beet is sometimes carried three or four miles in pipes for the same reason.

"Many of my readers may remember that it was not long ago proposed to manufacture the gas for the supply of London at the mouths of the coal mines, and convey it to the city in pipes, thus saving the transportation of the coal; but as the coke and mineral tar would still have remained to be disposed of, the operation would probably not have proved advantageous.

"Great economy in the production of petroleum has resulted from the application of cast-iron tubes to the wells instead of barrels; the oil is thus carried over the various inequalities of surface for three or four miles to the tanks on the railroads, and forced into them by steam engines. The price of transport is thus reduced one fifth."

† "The Austrian Government is making energetic efforts for the propagation of forests on the desolate waste of the Karst. The difficulties from drought and from the violence of the winds, which might prove fatal to young and even to somewhat advanced plantations, are very serious, but in 1866 upwards of 400,000 trees had been planted and great quantities of seeds sown. Thus far, the results of this important experiment are said to be encouraging. See the *Chronique Forestière* in the *Revue des Eaux et Forêts*, February, 1870.

"Later accounts state that the government nurseries of the Karst supplied between 1869–1872 26,000,000 young forest trees for planting, and that of 70,000 ash trees planted in the Karst, scarcely one failed to grow."

‡ "For information respecting the forests of Germany, as well as other European countries, see, besides the works already cited, the very valuable *Manuale d'Arte Forestale* of Siemoni, 2de edizione, Firenze, 1872."

over and more or less recently cleared for cultivation. There is probably not a single district in Russia which has not to deplore the ravages of man or of fire, those two great enemies of Muscovite sylviculture. This is so true, that clear-sighted men already foresee a crisis which will become terrible, unless the discovery of great deposits of some new combustible, as pit-coal or anthracite, shall diminish its evils.'*

"FORESTS OF UNITED STATES.

"I greatly doubt whether any one of the American States, except, perhaps, Oregon, has, at this moment, more woodland than it ought permanently to preserve, though, no doubt, a different distribution of the forests in all of them might be highly advantageous. It is, perhaps, a misfortune to the American Union that the State Governments have so generally disposed of their original domain to private citizens. It is true that public property is not sufficiently respected in the United States; and within the memory of almost every man of mature age, timber was of so little value in the northernmost States that the owners of private woodlands submitted, almost without complaint, to what would be regarded elsewhere as very aggravated trespasses upon them.† Persons in want of timber helped themselves to it wherever they could find it, and a claim for damages, for so insignificant a wrong as cutting down and carrying off a few pine or oak trees, was regarded as a mean-spirited act in a proprietor. The habits formed at this period are not altogether obsolete, and even now the notion of a common right of property in the woods still

* A foot-note of the author is omitted here.

† "According to the maxims of English jurisprudence, the common law consists of general customs so long established that 'the memory of man runneth not to the contrary.' In other words, long custom makes law. In new countries, the change of circumstances creates new customs, and, in time, new law, without the aid of legislation. Had the American colonists observed a more sparing economy in the treatment of their woods, a new code of customary forest law would have sprung up and acquired the force of a statute. Popular habit was fast elaborating the fundamental principles of such a code, when the rapid increase in the value of timber, in consequence of the reckless devastation of the woodlands, made it the interest of the proprietors to interfere with this incipient system of forest jurisprudence, and appeal to the rules of English law for the protection of their woods. The courts have sustained these appeals, and forest property is now legally as inviolable as any other, though common opinion still combats the course of judicial decision on such questions."

lingers, if not as an opinion at least as a sentiment. Under such circumstances it has been difficult to protect the forest, whether it belong to the State or to individuals. Property of this kind is subject to plunder, as well as to frequent damage by fire. The destruction from these causes would, indeed, considerably lessen, but would by no means wholly annihilate the climatic and geographical influences of the forest, or ruinously diminish its value as a regular source of supply of fuel and timber.

"It is evidently a matter of the utmost importance that the public, and especially land-owners, be roused to a sense of the dangers to which the indiscriminate clearing of the woods may expose not only future generations, but the very soil itself. Some of the American States, as well as the Governments of many European colonies, still retain the ownership of great tracts of primitive woodland. The State of New York, for example, has, in its northeastern counties, a vast extent of territory in which the lumberman has only here and there established his camp, and where the forest, though interspersed with permanent settlements, robbed of some of its finest pine groves, and often ravaged by devastating fires, still covers far the largest proportion of the surface. Through this territory the soil is generally poor, and even the new clearings have little of the luxuriance of harvest which distinguishes them elsewhere. The value of the land for agricultural uses is therefore very small, and few purchases are made for any other purpose than to strip the soil of its timber. It has been often proposed that the State should declare the remaining forest the inalienable property of the Commonwealth, but I believe the motive of the suggestion has originated rather in poetical than in economical views of the subject. Both these classes of considerations have a real worth. It is desirable that some large and easily accessible region of American soil should remain, as far as possible, in its primitive condition, at once a museum for the instruction of the student, a garden for the recreation of the lover of nature, and an asylum where indigenous tree, and humble plant that loves the shade, and fish and fowl and four-footed beast, may dwell and perpetuate their kind, in the enjoyment of such imperfect protection as the laws of a people jealous of restraint can afford them. The immediate loss to the public treasury from the adoption of this policy would be inconsiderable, for these lands are sold at low rates. The forest alone, economically managed, would, without injury, and even with benefit to its permanence and growth, soon yield a regular income larger than the present value of the fee.

"The collateral advantages of the preservation of these forests would be far greater. Nature threw up those mountains and clothed them with lofty woods, that they might serve as a reservoir to supply with perennial waters the thousand rivers and rills that are fed by the rains and snows of the Adirondacks, and as a screen for the fertile plains of the central counties against the chilling blasts of the north wind, which meet no other barrier in their sweep from the Arctic pole. The climate of Northern New York even now presents greater extremes of temperature than that of Southern France. The long-continued cold of winter is more intense, the short heats of summer even fiercer than in Provence, and hence the preservation of every influence that tends to maintain an equilibrium of temperature and humidity is of cardinal importance. The felling of the Adirondack woods would ultimately involve for Northern and Central New York consequences similar to those which have resulted from the laying bare of the southern and western declivities of the French Alps and the spurs, ridges, and detached peaks in front of them.

"It is true that the evils to be apprehended from the clearing of the mountains of New York may be less in degree than those which a similar cause has produced in Southern France, where the intensity of its action has been increased by the inclination of the mountain declivities, and by the peculiar geological constitution of the earth. The degradation of the soil is, perhaps, not equally promoted by a combination of the same circumstances, in any of the American Atlantic States, but still they have rapid slopes and loose and friable soils enough to render widespread desolation certain, if the further destruction of the woods is not soon arrested. The effects of clearing are already perceptible in the comparatively unviolated region of which I am speaking. The rivers which rise in it flow with diminished currents in dry seasons, and with augmented volumes of water after heavy rains. They bring down larger quantities of sediment, and the increasing obstructions to the navigation of the Hudson, which are extending themselves down the channel in proportion as the fields are encroaching upon the forest, give good grounds for the fear of irreparable injury to the commerce of the important towns on the upper waters of that river, unless measures are taken to prevent the expansion of 'improvements' which have already been carried beyond the demands of a wise economy.

"In the Eastern United States the general character of the climate, soil, and surface is such, that for the formation of very destructive torrents a much longer time is required than would be necessary in the mountainous provinces of Italy or of France. But the work of desolation has begun even there, and wherever a rapid mountain-slope has been stripped of wood, incipient ravines already plough the surface, and collect the precipitation in channels which threaten serious mischief in the future. There is a peculiar action of this sort on the sandy surface of pine-forests and in other soils that unite readily with water, which has excited the attention of geographers and geologists. Soils of the first kind are found in all the Eastern States; those of the second are more frequent in the exhausted counties of Maryland, where tobacco is cultivated, and in the more southern territories of Georgia and Alabama. In these localities the ravines which appear after the cutting of the forest, through some accidental disturbance of the surface, or, in some formations, through the cracking of the soil in consequence of great drought or heat, enlarge and extend themselves with fearful rapidity.

"In Georgia and in Alabama, Lyell saw 'the beginning of the formation of hundreds of valleys in places where the primitive forest had been recently cut down.' One of these, in Georgia, in a soil composed of clay and sand produced by the decomposition *in situ* of hornblendic gneiss with layers and veins of quartz, 'and which did not exist before the felling of the forest twenty years previous,' he describes as more than 55 feet in depth, 300 yards in length, and from 20 to 180 feet in breadth. Our author refers to other cases in the same States, 'where the cutting down of the trees, which had prevented the rain from collecting into torrents and running off in sudden land-floods, has given rise to ravines from 70 to 80 feet deep.'*

"Similar results often follow in the Northeastern States from cutting the timber on the 'pine plains,' where the soil is usually of a sandy composition and loose texture."

* "Lyell, *Principles of Geology*, 10th ed., vol. 1, 345–6."