GEOLOGICAL SURVEY OF KENTUCKY.

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ON THE ORIGIN

OF

THE GALENA DEPOSITS

OF THE

UPPER CAMBRIAN ROCKS OF KENTUCKY,

BY N. S. SHALER.

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The deposits of galena in the Cambrian district of the State differ in some important regards from those which have been observed in the sub-carboniferous limestone, although there is in both cases a general agreement in the circumstances of occurrence. In both cases these deposits are limited to true fissure veins of a peculiar type. In both regions they occur in limestones only, and are not observed in the overlying silicious and argillaceous rocks. The associated minerals in both cases are substantially the same, though differing in their proportions and general appearance. We are driven by the facts to the conclusion that all these veins have been formed by infiltration of water charged with the substances that form the vein matter, the cavity of the vein having been first developed by a movement of the rocks in which it is found. There are, however, differences of character between the galena veins of the Livingston district and those of Central Kentucky that compel us to make a strong line between them. As is shown by the report of Mr. Norwood (see reports Kentucky Geological Survey, first volume, new series), the veins in the Livingston district very often give indications of abrupt faulting, and, in some cases at least, of several successive vertical disturbances acting in the same spot. There seems to have been a good deal of irregularly acting dislocating force in this region, which did not result in the formation of distinct mountain curves, but expended itself in the numerous sharp breaks that have disturbed all this district.

I am inclined to attribute many of these veins of the Livingston district to this faulting action, combined with the shrinking of the whole rock system from the loss of heat and other changes.[*] The result was the formation of fissures of possibly great depth, the walls of which gaped apart, remaining perhaps closed near the surface, where there was perhaps only a small contraction, or, possibly, none at all. The next stage of the process seems to have been the infiltration of waters charged with carbonate of lead in solution, and its deposit by crystallizing action within these cavities. Subsequent changes brought about still further movements of the same character as those that formed the cavity at first, and through them the original deposits were often curiously broke up and mingled with other materials.

In the Cambrian district, particularly in Henry county, the tendency to faulting seems to have been much less than in the western field. All the crevices I have seen do not show any distinct vertical movement of the wall rocks, but seem to have been formed by lateral dislocation alone. It is not easy to determine the causes of this shrinkage in the mass of rock throughout this region, but the evidence of its occurrence is tolerably clear at all points. It is manifested in every line of the section by the breakage of the mass of rock into vertical crevices, which have become to a greater or less extent filled with clay and other substances. At some points these crevices indicate a reduction of at least one fifteenth of the horizontal dimensions of the rock mass. Generally these shrinkage

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[*] I am inclined to think that the general absence of mineral deposits in all the well-defined faults which I have seen in Kentucky is strong presumption against the occurrence of extensive mineral deposits in such breaks within this Commonwealth. The Pine Mountain fault, one of the most extensive and readily observable in the whole Appalachian district, has not yet given a trace of metallic deposits. The same is the case with the Kentucky River faults. In the case of the lode near Smithland, Livingston county, that on which the Royall mines are situated, there seems good evidence of a fault. With this evidence from other fissures, I should feel it necessary to examine with care for evidence as to the time of formation of the fault itself as distinguished from the vein stuff. These deep-reaching contraction fissures naturally form lines of weakness, along which faults would propagate themselves in case the rocks were submitted to a breaking strain tending to form such disruptions. In the case of the Royall mines and other openings on the fissure just referred to, this question would have little practical value, inasmuch as the vein stone at that point may be reasonably expected to extend quite through the Waverly rock, as well as the sub-carboniferous limestone, on account of the calcareous character of the former rock in its western extension.

Without taking up the history of these dislocations of Kentucky in detail—a matter which will be reserved for use of the special memoirs on the geology of the State—it may be worth while to say that all the facts as yet collected point to the conclusion that all the faults, in Eastern Kentucky at least, are of a comparative recent origin, probably dating from a time long after the action of the forces concerned in making the deposits in the galena veins.

cracks extend only through a foot or two of the beds in a continuous way, the different beds yielding at different points, so that nothing like a continuous crevice is found. On the other hand, from point to point, we have these continuous deep-reaching fractures with separation of the walls, which to my mind are certain indications of a contraction that has extended through a great thickness of beds, and differs only in the magnitude of its action from the small crevices so abundantly found throughout the rocks.

The deep-reaching crevices of considerable width seem most abundant where the small open joints are rare. In Campbell and the adjoining counties, where the limestone abounds in these open joints, I have never found an ore-bearing crevice; while in the counties within the Cambrian district, along the Kentucky river, where the rock is peculiarly free from small joints, these wide ore-bearing fissures are frequently found. We may, therefore, reasonably conclude that both these forms of fissuring are due to the same contraction of mass, and that some local conditions, possibly the difference in the massiveness of the beds, determine which shall be the type formed in any particular region.

The cleanness of these fractures, and the absence of all evidence of violence, is to my mind sufficient evidence that these fractures have not been attended by any wide-reaching movements. The fossil shells on the rock are often cut in two with perfect neatness, their broken edges being not in the least shattered or rubbed as they would have been had there been any such collision of the sides as is sure to occur where there has been true faulting. This is not the place for an exhaustive inquiry into the nature of the forces that have brought about this change in mass; but some idea of the nature of the forces involved is necessary to the comprehension of the condition under which the vein-stones that fill them have been formed.

There can be no doubt that this region was once buried under several thousand feet of strata, which have been worn away during the time since the emergence of the region from the sea. During the time these beds lay deep buried there was an accession of heat which may well have amounted to several hundred degrees of Farenheit. This expansion must have done much to pack the rocks together, and to bring about chemical changes attended by a loss of volume. When, therefore, the continued loss of heat, caused by the wearing away of the old rock covering, had greatly lowered the temperature, the tendency of the rock to contraction would be considerable. As against pressure rocks are tolerably elastic, but to tension they are much less so, and rend apart easily under its action; so that any considerable loss of heat would not be required in order to account for these deep-reaching rifts. A change of not over one hundred degrees Farenheit would be sufficient to cause the formation of a considerable number of rifts, probably as many as occur in this region.

The possibilities are that these rifts began to form with the first considerable decrease of temperature, and increased in width as time went on and cooling advanced. As will be seen from the figures in Mr. Norwood's report, there is a very general tendency of these veins to be grouped in the shape of two or three gashes placed near to each other. The immediate partitions are often thin walls, yet undisturbed by any violent movements. This affords another evidence of the tranquil nature of the movements involved in their production. It will also be seen that there is no evidence whatever of a vertical movement of the rocks on either side of the fissure. The beds lie at equal heights in both walls, and every feature of fault veins is quite wanting. We are therefore compelled to hold to the opinion that these veins are the product of shrinkage of the rocks.

Having now briefly discussed the formation of the fissures in which these deposits occur, it remains for us to examine the methods of accumulation of the deposits contained within them. This inquiry, though touching on the domain of abstract theory concerning the genesis of such veins, is necessary to any proper understanding of their character, and of the prospects of their downward extension.

The old view that attributed the formation of mineral veins to the ejection from a reservoir of molten matter of mineral substances, which penetrated along the passages leading towards the surface, has been quite abandoned as a usual explanation to be assigned to such phenomena. In its place has grown up the conviction that most veins are formed in essentially the same fashion as is the stalactitic material that accumulates in caverns, viz: by the deposition of matter dissolved by water in one part of its course through the crust of the earth and laid down at another.

The belief of metallurgists and others who have most studied the history of metals is, that the original condition of those substances was that of extensive dissemination, and that this local accumulation has been the result of actions that have come about in the changes of temperature, &c., taking place since the deposition of the beds containing the deposit.

Until within a few years this opinion, very general in its outlines, has been the accepted view as to the origin of metallic deposits. It will be seen that it is imperfect, in that it does not sufficiently explain the curious limitation of certain species of metals to certain geological formations.

In 1862 a decided advance towards a clearer theory was made in the report of J. D. Whitney on the lead district of Wisconsin, in which the ground was distinctly taken that the process of formation of mineral veins went on in something like the following manner, viz: First, the dissolving out from the rocks of the earth of the mineral substances which were originally widely distributed therein, and their transportation to the waters of the sea. Second, the precipitation of these materials by the action of the decaying organic life on the sea floor, which, as we know, is capable of effecting such work. Third, the concentration of these materials through the action of the various processes that build up the veins. The following extract from the work of Prof. Whitney will serve to show the fashion in which this was suggested by him. On account of the close general resemblance of the geological condition of the upper Mississippi lead region to the Kentucky lead district, I have, by permission of the author, made extensive extracts from his report.*

These important suggestions remained practically unconsidered and without addition until many years after their publication. In a course of unpublished lectures given by Professor Raphael Pumpelly at Harvard University in 1869–'70, the idea of the cöoperation of the secretive power of organic life in the series of actions leading to the formation of mineral veins was suggested and extensively discussed, though from a somewhat different point of view. For the first time the capacity of organic species to separate metals from the sea water and build them into their structure was publicly suggested as a means whereby the fixing of metals in strata could be brought about. In this process of concentration Professor Pumpelly gave great weight to the action of marine currents in accumulating masses of sea weeds and other organic substances on particular parts of the sea floor, and so leading to deposits in great part made up of the remains of animals which might contain some one metal in considerable quantities. By permission of Professor Pumpelly this lecture is published in the second appendix to this report.

In 1870 Dr. T. Sterry Hunt brought the matter to the notice of geologists in an extended discussion of the action of organic life in the localization of mineral substances. We seem to have here, as in many other cases in the process of scientific progress, the coincident and independent discovery of a series of facts by two observers, each working in ignorance of the other's researches. The first public announcement of this discovery was made by Professor Pumpelly; but priority, as determined by actual publication, is clearly to be awarded to Dr. Hunt.

The researches that have been made into the composition of sea water and of sea weeds has gone far to support this hypothesis as to the function of marine organic life in the

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*See Appendix No. I, taken from a "Report of a Geological Survey of the Upper Mississippi Lead Region, by J. D. Whitney, Albany, N. Y., 1862."

making of mineral deposits. There can be no reasonable doubt that all the substances which have been detected by chemists have their place in the universal solution of the sea. The presence of silver, gold, copper, and other metals in the sea water is evident on a concentration of its contents. Some of these substances exist in considerable quantities. The assertion even been made that the silver of the sea will amalgamate with the copper employed in sheathing ships, so that old copper long exposed to the moving sea may be worked for its silver won from the water. The idea prevails that this separation of silver by the copper takes place more rapidly on the west shore of South America than in any other region.

The researches of Forchhamer and others on the composition of marine invertebrate animals and plants long ago showed that there is a considerable amount of metallic substances laid up in the structure of marine forms, which, on their death and decay, would be laid down with the accumulating sediments of the sea floor. It is my impression, as above remarked, that this important function of organic life in the production of mineral deposits was first suggested by Professor Pumpelly in his lectures above referred to, of which no printed report was ever made. It is important to notice, however, that, as long ago as 1858, Dr. T. Sterry Hunt began a series of investigations as to the action of organic life in the deposition of various substances, such as carbonate and phosphate of lime, &c., which had been built into their structures, that led naturally to the inquiry into the important action of marine life in the deposition of metallic substances. A discussion of this important hypothesis will be found in the assembled papers of Dr. Hunt.*

It does not come within the province of this report to attempt an exhaustive inquiry into this question of the origin of these lead deposits of the upper Cambrian. From the suggestions already given, it will be seen that this balance of opinion among the best informed chemists and metallurgists inclines to the conclusion that organic life is closely concerned

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*See Appendix No. III at the end of this report.

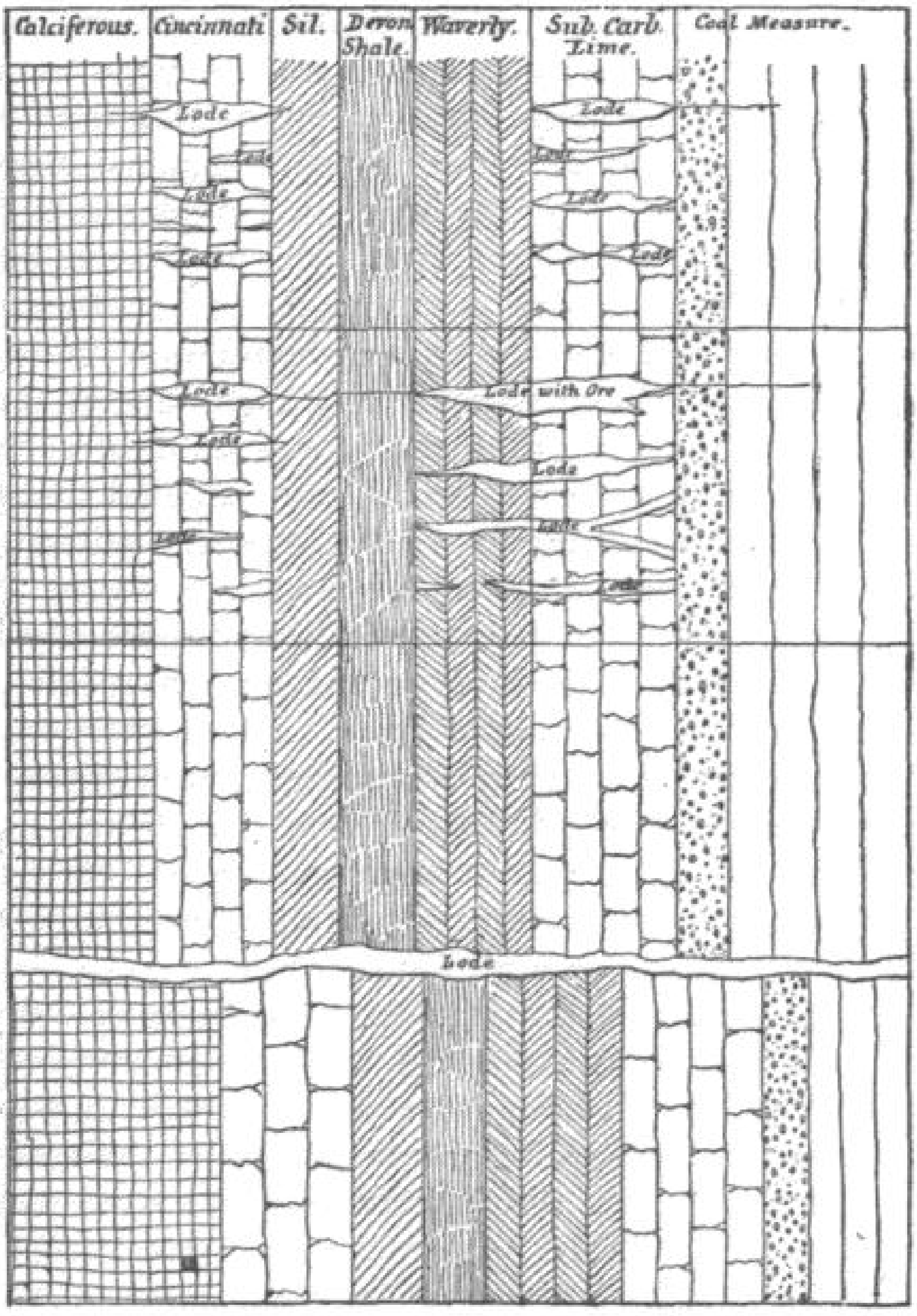
in the localization of the metallic deposits, at least in the little changed rocks, such as compose all our Kentucky formations, and that in this work the action takes place in two ways: *Firstly*, by the taking into the organic structure of the metallic substances which pass into the sea bottom on its decay. *Secondly*, by the effect of the gases, particularly the sulphuretted hydrogen, released by decay, in precipitating the metallic substances dissolved in the sea. The practical operation of these processes is somewhat as follows: The fixed, and to a certain extent the swimming, animals of the sea, taking this or that substance in their growth, deliver it up at their death to certain tracts of the ocean bottom, and in their decay take continually more of these substances into imprisonment in the accumulating sediment.

As this power of separating metallic substances varies in different species, it therefore differs in different sections of the ocean floor and in different periods in the earth's history. If this theory be true, then, other things being equal, we should expect to find that those formations which indicate the existence of abundant organic life on the sea floor where they are being deposited would be the most likely to furnish considerable quantities of metals. Such, in fact, we find to be the case wherever these deposits have been worked under similar conditions to those existing in the region we are now considering. The evidence cannot be safely regarded as affording a basis for definite and final assertion; but there can be no reasonable doubt that, in going downwards into rocks containing little evidence of organic life, we have reason to fear that we shall pass out of the richest part of a galena vein and into leaner territory. Some of the metal derived from the rock where it was deposited will, doubtless, often work downwards into the fissure when it runs in sandstones or other rocks where life has never been abundant. But this must be, in a good degree, accidental, as the deposit generally takes place at the point where the metal-charged waters oozed through the walls of the fissure. There is little reason to suppose that there could be more of the metallic substance in the sandstone or shale beds than in the limestone beds. Another reason to fear the unprofitable nature of galena veins in sandstone beds would be from the contraction of the fissure, owing to the change of rock. We have seen that the most of the veins found in Kentucky are the product of contraction or shrinkage taking place in the stratified rocks. This form of vein is always characterized by very variable width, and is likely to widen in the limestones and to contract in sandstones and shales.

The general character of the deposits of ore in the mineral veins of Kentucky may be the better understood when we consider some of the facts of distribution of these veins. The blue or Cambrian limestone abounds in these veins, especially in its upper part, where the organic life has left abundant fossil record of its existence. The equivalents of the Niagara series, rather carboniferous, have little trace of lead. The black or Ohio shale is almost without mineral beds of any importance; the same may be said of the Waverly series in Eastern Kentucky, where we find sandstones and argillaceous limestones rarely penetrated with lead-bearing rocks. When, however, we come up to the sub-carboniferous limestone, then, again, we find the lead-bearing veins in great abundance. Now when, as in Central Kentucky, we follow the line over which the carboniferous limestone has retreated, we are struck with the fact that, where it has been worn away from the lower lying beds, the Waverly and black or Ohio shale, these beds from which the carboniferous limestone has been stripped away, are characterized by the want of mineral veins, as above set forth. We have no reason to doubt that the limestone that once overlaid these beds was as well marked by its mineral veins as are the areas which still exist. We are, therefore, led to believe that these veins we find in the sub-carboniferous limestone do not extend into the subjacent sandstones and shales. It should, however, be distinctly noticed that this difference depends not upon the geological position of the rock, but on its mineralogical character; and that where, as in Western Kentucky, the Waverly series takes on the nature of a limestone, it may happen that it will protract the lead-yielding fissures downward to great depths. I am inclined to believe that the lead-yielding veins in that district may in some cases be followed about a thousand feet down before they pass into rock of a sandy constitution.

The question will, perhaps, be asked why, inasmuch as we find some of the ancient rocks, as gneiss, mica schist, and other similar materials, containing lead veins, there should be a basis for the idea that organic life is necessary for the concentration of such metals. This question opens one of the broad fields of geology, and it cannot be discussed in detail in this report. The answer can, however, be indicated in a general way. It is now the belief of most geologists that all the rocks now visible on the surface of the earth have been laid down on the sea floors by the action of water; that they were once limestones, sandstones, and shales, essentially like our familiar rocks, that still carry in their fossils and their structure most evident marks of their origin. These rocks, having been deep buried beneath subsequent accumulations of like materials, subjected to great and long continued pressure heat, and the manifold changes that go in their train, have gradually had their particles so re-arranged that their original character is often quite lost or only traceable by slender threads of evidence. In the vast periods of time, and amid the ever changing circumstances of these metamorphic rocks, the metals may have been carried from point to point, and from level to level, in the series of rocks, being again and again dissolved by heated and gas-containing waters, which took them up at one place to lay them down at another. The veins in the highly altered rocks, the mica schists, for instance, may have been originally laid down in some much higher rocks of another character, and only brought to their present level by the long-continued circulation of heated waters, being, perhaps, several times deposited and redissolved in the course of their downward journey. In our Kentucky rocks, however, we get but the first stage only of this migration of the particles of metal after their deposition in the organic remains. The metals have been concentrated into fissures in the immediate neighborhood of their deposition, but have been subjected to no further change.

The following figure will show, in a diagrammatic way, the apparent condition of the Kentucky series of rocks. It should be understood that this figure is intended as an illustration of an opinion rather than as a graphic representation of the facts:



Viens of Eastern Ky.
N. B.—The Waverly in Eastern Kentucky is a Sandstone.

Veins in Western Ky.
N. B.—The Waverly in Western Kentucky is a Limestone.

True fissure vein such as may occur in Western Ky.

DIAGRAM SHOWING RELATIONS OF MINERAL VEINS

It will be noticed that this diagram indicates generally vertical fissures with tolerably regular walls, all clearly the work of a contraction of the mass. On examining Professor Whitney's work, "The Lead Region of the Upper Missouri," it will be seen that there have been extensive deposits of the lead and associated substances in ordinary caverns in that region—a large part of the workable deposits coming from beds that have been formed in caverns rather than as fissures. Possibly some of the lead deposits of Western Kentucky, occurring in the carboniferous limestones, may also be regarded as occupying caverns rather than fissures; but at this time I am quite convinced that the evidence is rather against this view and in favor of the theory that this class of deposits has never, in this region, been found in caverns excavated by water. I have carefully observed many such underground channels, both in the Cambrian and Sub-carboniferous limestones, with a view to ascertaining whether any such deposit is now going on, with the definite result that not a trace of such action is observable at the present time. I am satisfied that the uppermost caves in Kentucky date back at least a million of years,* and that they were probably in existence during the middle Tertiary period; yet in none of them is there the least trace of the deposition of lead. It seems to me that this fact clearly proves that the formation of these veins is most explicable by the supposition that they were segregated while the rocks were subjected to conditions of heat that do not now exist in them. At the same time it must be said that their mechanical condition forbids the supposition that they have ever been subjected to any very high temperature.

To sum up in brief the general condition of our Kentucky vein metals, we may make the following propositions, viz:

1st. That the fissures or veins in which they occur have generally been formed by the shrinkage of the rocks in which they are found, and not by the deeper-seated causes which form fault veins.

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*See Antiquity of the Caverns and Cavern Life of the Ohio Valley, Memoirs Kentucky Geological Survey, volume I, part I, 1876.

2d. That these fissures, dependent for their origin on the peculiarities of constitution of particular beds, cannot safely be expected to continue indefinitely downwards below the level of the beds in which they are seen.

3d. That the absence of metallic veins in the sandstones that were originally overlaid by limestones, which limestones are vein-bearing, is a corroboration of the view that these veins are limited to the limestone rocks.

4th. That the general presence of metalliferous veins in the limestones of the State, and their general if not universal absence in the sandstones, is a strong proof of the truth of the theory that assigns to organic life the function of separating these metals from the sea and laying them down in the stratified rocks.

5th. That the cycle of change of metals, as, indeed, of all substances, is as follows: Dissolved from the earth by the water, which is aided in its work by its contained gases and heat, they find their way to the sea; then the organisms living in the waters or on the bottom, select the substances according to their peculiar organic laws; built into the growing deposits of the sea bottom, they become part of the earth's crust, and come again within the action of those forces that work them into their concentrated state, or, mayhap, wash them again into the sea, and so repeat the eternal circle.

In the appendix to this report I have, by permission of the authors, reprinted extracts from the writings of Professors J. D. Whitney and Raphael Pumpelly and Dr. T. Sterry Hunt, thus bringing together all the important contributions known to me that bear on this question.

The reader is requested to bear in mind that the views above suggested, though they seem to satisfy the facts better than is usually the case in geological theories, must not be taken as matters of final demonstration. There can be no doubt that the balance of probabilities is greatly in their favor, and that they may fairly be made the basis of a judgment by those who seek even the least light where else would be only darkness.

With reference to the economic bearing of these conclusions above set forth, little needs be said. The economic side of the problem is not greatly affected thereby, save in the conclusion that few of our lead deposits, if any, may reasonably be expected to be continuous to great depths or to improve in descending. The reports of Dr. Peter make it plain that all our lead ores are singularly poor in silver; in no case has enough been found to warrant extraction. With careful mining some of the lodes will possibly pay for working; but there can be no doubt that at least half a dozen other sources of mineral wealth within the State promise a better return for capital and enterprise. Already there has been a large amount of money expended in the opening of lead ores in the State; probably not less than half a million dollars has been spent in such workings. Very little lead has been marketed. I doubt whether four hundred tons have ever been obtained from all the workings put together, and but two or three openings can now be said to be promising in their appearance. I feel, therefore, compelled to say, that however single ventures may turn out, the prospect of the industry to the Commonwealth is by no means good.

APPENDIX I.

[From a Report on the Upper Mississippi Lead Region by Professor J. D. Whitney, reprinted by permission of the Author.]

"In view of all these facts, we consider it as a matter settled beyond all possibility of doubt, that the lead deposits of the Northwest must have been introduced into the fissures from above, and by precipitation from a solution. In reference to this last clause, we have not thought it necessary to adduce any evidence to disprove the theory of the igneous origin of the ore, or of its having been brought up from below, either by sublimation, or by actual injection. Since, however, both of these ideas have been maintained by different persons writing on the region, although every fact seems to be entirely opposed to any hypothesis of igneous action, it may be proper to sum up as concisely as possible the evidence in favor of aqueous deposition.

"1st. The generally recognized aqueous origin of the sulphurets: deposits of sulphurets of iron and other metals are frequently produced accidentally or intentionally in the chemist's laboratory, by the decomposition of solutions containing the metals by sulphuretted hydrogen.

"2d. The occurrence of the sulphurets of lead and iron in the lead region, in forms which they could not have assumed, except as deposited from a solution—as in the form of casts of fossils, and in connection with stalactites and stalagmitic masses of calcite. An instance of this kind is to be seen in the Wheatley collection at Union College, and is shown in the annexed wood-cut, which represents a large stalagmite, with a small mass of galena on the end of it, in a position which it would be difficult to imagine it to have reached, except in solution, dropping from above, exactly as the rest of the stalagmite was formed. Instances have been mentioned

Stalagmite with Galena

to me by the miners (I have not met with such myself) of stalagmites made up of alternating layers of galena and calc. spar. The replacement of organic forms by galena is not infrequent, and that by pyrites is very common; blende has never been met with in this relation, so far as is known.

"3d. The impossibility, absolute and entire, of the introduction of the ore into the crevices from below, either as a molten mass or in the form of a sublimate: this point has been already sufficiently insisted on. It is inconceivable that any one at all familiar with chemistry, or mining geology, should have ever imagined the possibility of the igneous origin of these ores.

"If, then, we inquire by what agent the sulphuretted combinations of the metals now found so abundantly disseminated through the lead region could have been deposited in their present position, we need not look far for an answer, since there is but one agent capable of effecting it, namely sulphuretted hydrogen gas. This decomposes nearly all metallic solutions, and precipitates the metals in the form of sulphurets, provided the resulting sulphuret is one insoluble in the medium in which the decomposition takes place. If, then, the metals zinc, lead, and iron were present, in solution, in the oceanic waters at the time of the deposition of the lead-bearing strata, or if the strata became impregnated with these metallic substances, by the infiltration of waters charged with their salts through them, then all that would be needed to produce a deposition of the sulphurets would be a source of sulphuretted hydrogen gas, slowly disengaged in or beneath the rocks permeated by the metalliferous solutions.

"That the oceanic waters were highly impregnated with metalliferous salts during the early geological periods seems not improbable, from the fact that the lower formations are those which contain the largest deposits of ores: these are found both in the unaltered sedimentary rocks, and in those which have undergone metamorphism. The palæozoic strata, and especially the Lower Silurian groups, all over the world, are emphatically the great store-houses of the metals. The azoic rocks, on the contrary, are poor in ores, with the exception of such as have been introduced into them by direct igneous or intrusive action. Thus, in this country, for instance, the lowest series of strata, or those deposited, so far as the evidence goes, before the appearance of organic life on the globe, are but scantily supplied with any of the metals except iron, which occurs in this geological position in the oxidized form, and in mountain masses. The Lower Silurian rocks, on the other hand, either in their unaltered state, as at the West, or as metamorphosed in the Atlantic States, are the seat of active mining operations for a variety of metals.

"It will be argued, of course, that, the crust of the earth being thinner during the earliest geological periods, thermal springs conveying metalliferous solutions could more easily have found their way to the surface in regions broken up by faults and dykes, so that the abundance of ore deposits would be due rather to the facility of access from below, than to the pre-existing condition of the oceanic waters above. But in regions like those of the Mississippi Valley, where there are no dykes or intrusive masses of igneous matter, and where the formations have been so slightly disturbed, since their deposition, as to make it exceedingly improbable that the ores they contain could have been introduced from below, we are driven to the necessity of presupposing their existence in the oceanic waters, either during the deposition of the metalliferous formation, or after it had taken place.

"That the appearance of the first considerable deposits of metalliferous ores in the Northwest should be closely connected with the introduction of animal life in profusion in that region, seems an important fact, which should be carefully considered in this connection. In all the thick mass of the Potsdam sandstone, from 300 to 500 feet in vertical development, there are nothing more than the merest traces of ores, and none of lead or zinc, so far as known. The insignificant deposits of iron and copper in this sandstone are exclusively in the oxidized form. In the Lower Magnesian limestone, which is next above, and whose lithological character is in every respect as favorable for the deposition and retention of metalliferous substances as is that of the lead-bearing rock above, we have only a few irregular deposits of galena, in the upper part of the formation, so that there is a thickness of 600 to 800 feet of stratified rocks above the azoic, which is almost absolutely barren of metallic ores. It is not until we rise into the Blue limestone that noteworthy quantities of any of the metals are found, and it is precisely here that the evidences of organic life begin to be abundant; portions of this group of strata are almost exclusively made up of the remains of animals, and these are nowhere more abundant than in the immediate vicinity of some of the heaviest deposits of the ores of lead and zinc. In the Lower Magnesian, the only traces of fossils yet discovered are in the upper portion of this rock, while the Potsdam sandstone is, except in a few extremely circumscribed localities, completely destitute of animal or vegetable remains. The same is true of the Upper sandstone, which is alike characterized by the entire absence of any traces of organic life or of metalliferous ores.

"It is hardly possible, in view of these facts, not to recognize a general law connecting the absence of the mineral deposits in the non-fossiliferous portions of the stratified groups with their abundance in those which contain organic remains. Whether we suppose the metalliferous solutions to have originated below, and to have been conveyed upwards by thermal springs, or whether we suppose them to have been contained in the waters of the ocean, we are, in either case, equally dependent on some conditions connected with the rocks themselves to account for the deposition or non-deposition of the metalliferous ores in the rocks in question. In the first named case, we should have to account for the zinc and lead solutions having been conveyed through rocks of precisely the same lithological character as those above in which deposition really did take place, without leaving a trace of their presence; in the other view, we should be called on to give a reason why no precipitation from the oceanic waters took place, while either the silicious or dolomitic strata were depositing, with a thickness of several hundred feet. To suppose that the ore-depositing springs could have passed through so great a vertical range of rock without a portion, at least, of the metallic substances having been left behind, we must assume that there was some cause to favor deposition present in the upper strata which was absent in the lower.

"The agent, then, which we conceive to have been efficient in producing the deposits of the metals which are found in the region in question, was the organic matter of the Blue limestone and the lower beds of the galena; which, either by its reducing action, while undergoing decomposition, acted on the sulphates of the metals held in solution in the surrounding waters, and converted them into sulphurets; or, still more directly, generating sulphuretted hydrogen from the sulphur which they themselves contained, furnished the necessary material for the precipitation of the metals as sulphurets.

"It has been demonstrated by repeated experiments, as well as by observation of natural phenomena, that organic substances undergoing decomposition in solutions impregnated with the sulphates of the metals cause a precipitation of the metal in the form of a sulphuret. The immense quantity of pyrites found in connection with all the coal beds of the West may be here referred to as evidence of this kind of chemical action. No other combination of iron than the sulphuret is found in the coal beds, and it is hardly possible to find a fragment of coal, however small, which has not some of this substance attached to it, or intersecting it in thin plates and veins. As we have in the strata of the Blue limestone the most fossiliferous portion of the whole series of rocks, many beds of it being made up almost exclusively of fragments of shells, we are not at a loss for organic matter, and it is especially in the neighborhood of the productive openings, in those districts where the mining is done in the Blue limestone, that the fossils are most abundant. Thus, at the Crow Branch diggings, the stuff thrown out from the pipe-clay opening is a mass of shells, many of which have been themselves converted into pyrites. The same is true of the openings in this geological position near Mineral Point.

"The immense number of remains of marine plants, which we have spoken of in a previous chapter as occurring in the lower and upper beds of the Galena limestone, may here be adverted to, in connection with the investigations of Forchhammer,[*] who has shown that many sea-weeds contain a large amount of sulphuric acid, the quantity in one instance being equal to 8.5 per cent. of the weight of the dried plant. He mentions that, in the vicinity of Copenhagen, the disengagement of sulphuretted hydrogen from the decomposing sea-weeds on the coast is often so great as to blacken the silver in the houses, at a considerable distance. Here, then, we have an ample source of sulphur to enter into combination with the iron and other metals contained in the sea-water in which the Galena limestone was deposited, which rock we conceive to have been made up in no small degree of the remains of this class of plants. No one can deny that we have, in the conditions set forth above, a *possible* means for the production of the deposits of the metals which have been described in the preceding pages. And as we conceive it to have been clearly shown that all other modes of deposition were impossible—that is to say, requiring conditions which have not existed in the lead region—we are forced to accept the theory advanced above, which is essentially that advocated by the author of this report six years ago, in the 'Metallic Wealth of the United States.'

"There are many points requiring farther elucidation, in connection with the formation of the lead-bearing crevices and openings; but it will be necessary to defer the consideration of them to another occasion, as this report has already swollen to an unexpected size.

"One or two conditions we may touch briefly upon before closing this section. The first is, the probable reason why the east and west crevices are so much more open, through a

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[*] See Bischof's Lehrbuch der Chemischen und Physikalischen Geologie, i, 925; and Report of the British Association for 1844.

large part of the lead region, while the norths and souths are, to a considerable extent, filled with sheet ore, as has been previously set forth. We explain this by referring to the gradual opening of the east and west crevices by an uplift of the region along an east and west axis: one or more undulatory movements of the strata, if effected in this direction, would necessarily tend to open the fissures running in the same direction as the axis of upheaval. The fissures being thus expanded, so as to give a passage to the system of under-ground drainage, they would become worn out into such shapes as we find them to have at present, while the norths and souths, remaining much more tightly closed, would show this effect in a less marked degree, as is the case in the lead region generally.

"Another question which will naturally be asked in reference to the views advanced above, is this: why, if the metalliferous solutions from which the ore deposits of the lead region were thrown down were diffused through the oceanic waters, there was not a precipitation of the metallic sulphurets over every part of the valley of the Upper Mississippi? or why is the productive mining ground confined to a limited area, while over a vast extent of country, for all that can be seen on the surface, there is no reason why equally important deposits should not exist?

"To this we reply, that we believe it would be found that, were the earliest highly fossiliferous formations everywhere exposed, they would be found to a considerable extent impregnated with the sulphurets of lead, zinc, iron, &c.; and in proof of this we refer to the fact that the Silurian, and especially the Lower Silurian rocks, are much more metalliferous than any other series of strata occupying the same area and with the same thickness. But these are not commonly exposed, being almost everywhere covered by other groups. Where metalliferous ores do exist in the upper strata, nothing forbids the belief that they may have been derived from previously deposited masses below, carried up in solution by thermal springs or otherwise. If the original conditions under which the ores were deposited in the lower rocks were not favorable to their segregation in large masses—as was the case in the lead region, where the rock was intersected by numerous fissures—then the deposition would take place in a more diffused manner, and we might have a mass of strata impregnated with ore, in small particles, which would thus be liable to oxydation, and would easily be dissolved out and transferred to the upper strata by thermal springs rising through them from beneath.

"To recapitulate as briefly as possible. The oceanic waters, during the earliest geological epochs, may have been, and very probably were, impregnated with metallic salts, although not to such an extent as to prevent the development of organic life. When this development took place, if the circumstances were otherwise favorable, by the reducing action of the decaying organic matter entombed in the strata, or by that of plants containing sulphuric acid, the metalliferous combinations in the surrounding waters were decomposed, and the metals precipitated as sulphurets. These were collected by segregation in masses of considerable size, when the rocks had the necessary lithological character, and when crevices, fissures, or cavities existed, in which these masses could find room for their formation. When this was not the case, the strata were impregnated with metalliferous substances, which were diffused through the mass of rock, and which may afterwards have afforded an almost inexhaustible magazine of material to be drawn upon for the formation of mineral veins and other deposits in the overlying rocks.

"It is believed that with the adoption of these views some facts may be explained, with regard to the occurrence of ores in mineral veins and other forms of deposit, which have not hitherto been well understood: the subject will be farther discussed, however, in another place, as a sufficient space in this report has already been occupied with theoretical views."

APPENDIX II.

[From the Origin of Metalliferous Deposits by Dr. T. Sterry Hunt.]

"There are about sixty bodies which chemists call elements; the simplest forms of matter which they have been able to extract from the rocky crust of our earth, its waters, and its atmosphere. These substances are distributed in very unequal quantities, and in very different manners. As regards the frequency of these elements in nature, neglecting for the present those which constitute air and water, and confining ourselves to the solid matters of the earth's crust, there are a few which are exceedingly abundant, making up nine tenths, if not ninety-five hundreds, of the rocks so far as known to us. The elements of which silica, alumina, lime, magnesia, potash, and soda are oxides are very common, and occur almost everywhere. There are others which are much rarer, being found in comparatively small quantities. Many of these rarer elements are, however, of great importance in the economy of nature. Such are the common metals and other substances used in the arts, which occur in nature in quantities relatively very minute, but which have been collected by various agencies, and thus made available for the wants of man. It is chiefly of the well known metals, iron, copper, silver, and gold, that I propose to speak; but there are two other elements, not classed among the metals, which I shall notice for the reason that their history is extremely important, and will, moreover, enable us to comprehend more clearly some points in that of the metals themselves. I speak of phosphorus and iodine.

"You all know the essential part which the former of these, combined as phosphate of lime, plays in the animal economy, in the formation of bones; and how plants require for their proper growth and development a certain amount of phosphorus. Ordinary soils contain only a few thousandths of this element, yet there are agencies at work in nature which gather this diffused phosphorus together in beds of mineral phosphates and in veins of crystalline apatite, which are now sought to enrich impoverished soils. Iodine, an element of great value in medicine and in the art of photography, is widely distributed, but still rarer than phosphorus; yet it abounds in certain mineral waters, and is, moreover, accumulated in marine plants. These extract it from the waters of the sea, where iodine exists in such minute quantities as almost to elude our chemical tests. (See the Appendix, page 237.)

"There are probably no perfect separations in nature. We cannot, without great precautions, get any chemical element in a state of absolute purity, and we have reason to believe that even the rarest elements are everywhere diffused in infinitesimal quantities. The spectroscope, which we have lately learned to apply to the investigation alike of the chemistry of our own earth and of other worlds once supposed to be beyond the chemist's ken, not only demonstrates the very wide diffusion of various chemical elements here on the earth, but shows us that very many of them exist in the sun. If we accept, as most of us are now inclined to do, the nebular hypothesis, and admit that our earth was once, like the sun of to-day, an intensely heated vaporous mass; that it is, in fact, a cooled and condensed portion of that once great nebula of which the sun is also a part, we might expect to find all the elements now discovered in the sun distributed throughout this consolidated globe. We may speculate about the condensation of some of these before others, and their consequent accumulation in the inner parts of the earth; but the fact that we have all the elements of the solar envelope (together with many more) in the exterior portions of our planet, shows that there was, at least, but a very partial concentration and separation of these elements during the period of cooling and condensation. The superficial crust of the earth, from which all the rocks and minerals which we know have been generated, must have contained, diffused through it, from the earliest time, all the elements which we now meet with in our study of the earth, whether still diffused, or accumulated, as we often find the rarer elements, in particular veins or beds.

"The question now before us is, how have these elements thus been brought together, and why is it that they are not all still widely and universally diffused? Why are the compounds of iron in beds by themselves, copper, silver, and gold gathered together in veins, and iodine concentrated in a few ores and certain mineral waters? That we may the better discern the direction in which we are to look for the solution of this problem, let us premise that all of these elements, in some of their combinations, are more or less soluble in water. There are, in fact, no such things in nature as absolutely insoluble bodies, but all, under certain conditions, are capable of being taken up by water, and again deposited from it.*

"The alchemists sought in vain for a universal solvent; but we now know that water, aided in some cases by heat, pressure, and the presence of certain widely distributed substances, such as carbonic acid and alkaline carbonates and sulphides, will dissolve the most insoluble bodies; so that it may, after all, be looked upon as the long-sought-for alkahest or universal menstruum.

"Let us now compare the waters of rivers, seas, and subterranean springs, thus impregnated with various chemical elements, with the blood which circulates through our own bodies. The analysis of the blood shows it to contain albuminoids which go to form muscle, fat for the adipose tissues, phosphate of lime for the bones, fluorides for the enamel of the teeth, sulphur, which enters largely into the composition of the hair and nails, soda, which accumulates in the bile, and potash, which abounds in the flesh-fluid. All of these are dissolved

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*It is well known that many chemical compounds, when first generated by double decomposition in watery solutions, remain dissolved for a greater or less length of time before separating in an insoluble condition. The solubility of recently precipitated carbonate of lime in water holding certain neutral salts, as already described (*ante*, page 149), is a fact in the same order. In this connection may also be recalled the great solubility in water of silicic, titanic, stannic, ferric, aluminic, and chromic oxides when in what Graham has called their colloidal state. There is reason to believe that silicates of insoluble bases may assume a similar state, and it will probably one day be shown, that, for the greater number of those oxygenized compounds which we call insoluble, there exists a modification soluble in water.

in the blood, and the great problem for the chemical physiologist is to determine how the living organism gathers them from this complex fluid, depositing them here and there, and giving to each part its proper material. This selection is generally ascribed to a certain vital force, peculiar to the living body. I shall not here discuss the vexed question of the nature of the force which determines the assimilation from the blood of these various matters for the needs of the animal organism, further than to say that modern investigations tend to show that it is only a subtler kind of chemistry, and that the study of the nature and relation of colloids and crystalloids, and of the phenomena of chemical diffusion, promises to subordinate all these obscure physiological processes to chemical and physical laws.

"Let us now see how far the comparison which we have made between the earth and an animal organism will help us to understand the problem of the distribution of minerals in nature; how far water, the universal solvent, acting in accordance with known chemical and physical laws, will cause the separation of the mixed elements of the earth's crust, and their accumulation in veins and beds in the rocks. The subject is one of great importance to the geologist, who has to consider the genesis of the various rocks and ore-deposits, and the relations, which we are only beginning to understand, between certain metals and particular rocks, and between certain classes of ores and peculiar mineralogical and geological conditions. It is at the same time a vast one, and I can now only give you a few illustrations of the chemistry of the earth's crust, and of the laws of the terrestrial circulation, which I have compared to that of the blood distributing throughout the animal frame the elements necessary for its growth. The analogy is not altogether new, since a great French geologist, Elie de Beaumont, has already spoken of a terrestrial circulation in regard to certain elements in the earth's crust; though he has not, so far as I am aware, carried it out to the extent which I now propose to do in my attempt to explain some of the laws which have presided over the distribution of metals in the earth.

"The chemist in his laboratory takes advantage of changes of temperature, and of the action of various solvents and precipitants, to separate, in the humid way, one element from another; but to these agencies, in the economy of nature, are added others which we have not yet succeeded in imitating, and which are exerted only in growing animals and plants. I repeat it; I do not wish to say that these latter processes are different in kind from those which we command in our laboratories, but rather that these organisms control a far finer and more delicate chemical and physical apparatus than we have yet invented. Plants have the power of selecting from the media in which they live the elements necessary for their support. The growing oak and the grass alike assimilate from the air and water the carbon, hydrogen, nitrogen, and oxygen which build up their tissues, and at the same time take from the soil a portion of phosphorus, which, though minute, is essential to the vegetable growth. The acorn of the oak and the grass alike become the food of animals, and the gathered phosphates pass into their bones, which are nearly pure phosphate of lime. In like manner the phosphates from organic waste and decay find their way to the sea, and through the agency of marine vegetation become at last the bony skeletons of fishes. These are, in turn, the prey of carnivorous birds, whose exuviæ form on tropical islands beds of phosphatic guano. A history not dissimilar will explain the origin of beds of coprolites and of some other deposits of mineral phosphates. [By whatever means the phosphates have been first concentrated, it appears from the recent studies of Sollas that the so-called coprolites of the green-sand in England result from a petrifaction of sponges by dissolved phosphates, and similar observations have been made by Edwards with regard to the guano of the Chincha Islands.]

"But again, these plants or these animals may perish in the sea and be buried in its ooze. The phosphates which they have gathered are not lost, but become fixed in an insoluble form in the clayey matter; and when, in the revolutions of ages, these sea-muds, hardened to rock, become dry land, and crumble again to soil, the phosphates are there found ready for the wants of vegetation.

"Most of what I have said of phosphates applies equally to the salts of potash, which are not less necessary to the growing plant. From the operation of these laws it results that neither of these elements is found in large quantities in the ocean. This great receptacle of the drainage from the land contains still smaller quantities of iodine; in fact, the traces of this element present in sea-water can scarcely be detected by our most delicate tests. Yet marine plants have the power of separating this iodine, and accumulating it in their tissues, so that the ashes of these plants are not only rich in phosphates and in potash-salts, but contain so much iodine that our supplies of this precious element are almost wholly derived from this source, and that the gathering and burning of sea-weed for the extraction of iodine is in some regions an important industry. When this marine vegetation decays, the iodine which it contains appears, like the potash and phosphates, to pass into combination with metals, earths, or earthy phosphates, which retain it in an insoluble state, and in certain cases yield it to percolating saline solutions, which thus give rise to springs rich in iodine.

"In all of these processes the action of organic life is direct and assimilative, but there are others in which its agency, although indirect, is not less important. I can hardly conceive of an accumulation of iron, copper, lead, silver, or gold, in the production of which animal or vegetable life has not either directly or indirectly been necessary, and I shall begin to explain my meaning by the case of iron. This, you are aware, is one of the most widely diffused elements in nature; all soils, all plants, contain it; and it is a necessary element in our blood. Clays and loams contain, however, at best, two or three hundredths of the metal, but so mixed with other matters that we could never make it available for the wants of this iron age of ours. How does it happen that we also find it gathered together in great beds of ore, which furnish an abundant supply of the metal? The chemist knows that the iron, as diffused in the rocks, exists chiefly in combination with oxygen, with which it forms two principal compounds: the first, or protoxide, which is readily soluble in waters impregnated with carbonic acid or other feeble acids; and the second, or peroxide, which is insoluble in the same liquids. I do not here speak of the magnetic oxide, which may be looked upon as a compound of the other two, neutral and indifferent to most natural chemical agencies. The combinations of the first oxide are either colorless or bluish or greenish in tint, while the peroxide is reddish-brown, and is the substance known as iron-rust. Ordinary brick-clays are bluish in color, and contain combined iron in the state of protoxide, but when burned in a kiln they become reddish, because this oxide absorbs from the air a further proportion of oxygen, and is converted into peroxide. But there are clays which are white when burned, and are much prized for this reason. Many of these were once ferruginous clays, which have lost their iron by a process everywhere going on around us. If we dig a ditch in a moist soil which is covered with turf or with decaying vegetation, we may observe that the stagnant water which collects at the bottom soon becomes coated with a shining, iridescent scum, which looks somewhat like oil, but is really a compound of peroxide of iron. The water as it oozes from the soil is colorless, but has an inky taste, from dissolved protoxide of iron. When exposed to the air, however, this absorbs oxygen, and the peroxide is formed, which is no longer soluble, but separates as a film on the surface of the water, and finally sinks to the bottom as a reddish ochre, or, under somewhat different conditions, becomes aggregated as a massive iron-ore. A process identical in kind with this has been at work at the earth's surface ever since there were decaying organic matters, dissolving the iron from the porous rocks, clays, and sands, and gathering it together in beds of iron-ore or iron ochre. It is not necessary that these rocks and soils should contain the iron in the state of protoxide, since these organic products (which are themselves dissolved in the water) are able to remove a portion of the oxygen from the insoluble peroxide, and convert it into the soluble protoxide of iron, being themselves in part oxidized and converted into carbonic acid in the process.

"We find in rock formations of very different ages beds of sediments which have been deprived of iron by organic agencies, and near them will generally be found the accumulated iron. Go into any coal region, and you will see evidences that this process was at work when the coal-beds were forming. The soil in which the coal-plants grew has been deprived of its iron, and when burned turns white, as do most of the slaty beds from the coal-rocks. It is this ancient soil which constitutes the so-called fire-clays, prized for making bricks which, from the absence of both iron and alkalies, are very infusible. Interstratified with these we often find, in the form of ironstone, the separated metal; and thus from the same series of rocks may be obtained the fuel, the ore, and the fire-clay.

"From what I have said it will be understood that great deposits of iron ore generally occur in the shape of beds; although waters holding the compounds of iron in solution have, in some cases, deposited them in fissures or openings in the rocks, thus forming true veins of ore, of which we shall speak further on. I wish now to insist upon the property which dead and decaying organic matters possess of reducing to protoxide, and rendering soluble, the insoluble peroxide of iron diffused through the rocks; and reciprocally the power which this peroxide has of oxidizing and consuming these same organic matters, which are thereby finally converted into carbonic acid and water. This last action, let me say in passing, is illustrated by the destructive action of rusting iron bolts on moist wood, and the effect of iron stains in impairing the strength of linen fibre.

"We see in the coal formation that the vegetable matter necessary for the production of the iron-ore beds was not wanting; but the question has been asked me, where are the evidences of the organic material which was required to produce the vast beds of iron-ore found in the ancient crystalline rocks? I answer that the organic matter was, in most cases, entirely consumed in producing these great results; and that it was the large proportion of iron diffused in the soils and waters of these early times, which not only rendered possible the accumulation of such great beds of ore, but oxidized and destroyed the organic matters which in later ages appear in coals, lignites, pyroschists, and bitumens. Some of the carbon of these early times is, however, still preserved in the form of graphite, and it would be possible to calculate how much carbonaceous material was consumed in the formation of the great iron-ore beds of the older rocks, and to determine of how much coal or lignite they are the equivalents.

"In the course of ages, however, as a large proportion of the once diffused iron-oxide has become segregated in the form of beds of ore, and thus removed from the terrestrial circulation, the conditions have grown more favorable for the preservation of the carbonaceous products of vegetable life. The crystalline magnetic and specular oxides, which constitute a large proportion of the ores of this metal, are almost or altogether indifferent to the action of organic matter. When, however, these ores are reduced in our furnaces, and the resulting metal is exposed to the oxidizing action of a moist atmosphere, it is again converted into iron-rust, which is soluble in water holding organic matters, and may thus be made to enter once more into the terrestrial circulation.

"There is another form in which iron is frequently concentrated in nature, that of sulphide, and most frequently as the bisulphide, known as iron-pyrites. This substance is found both in the oldest and the newest rocks, and like the oxide of iron, is even to-day forming in certain waters and in beds of mud and silt, where it sometimes takes a beautifully crystalline shape. What are the conditions in which the sulphide of iron is formed and deposited, instead of the oxide or carbonate of iron? Its production depends, like these, on decaying organic matters. The sulphates of lime and magnesia, which abound in sea-water, and in many other natural waters, when exposed to the action of decaying plants or animals, out of contact of air, are, like peroxide of iron, deoxidized, and are thereby converted into soluble sulphides; from which, if carbonic acid be present, sulphuretted hydrogen gas is set free. Such soluble sulphides, or sulphuretted hydrogen, are the reagents constantly employed in our laboratories to convert the soluble compounds of many of the common metals, such as iron, zinc, lead, copper, and silver, into sulphides, which are insoluble in water and in many acids, and are thus conveniently separated from a great many other bodies. Now, when in a water holding iron-oxide, sulphates are also present, the action of organic matter, deoxidizing the latter, furnishes the reagent necessary to convert the iron into a sulphide; which in some conditions, not well understood, contains two equivalents of sulphur for one of iron, and constitutes iron-pyrites. I may here say that I have found that the unstable protosulphide, which would naturally be first formed, may, under the influence of a persalt of iron, lose one half of its combined iron; and that from this reaction a stable bisulphide results. This subject of the origin of iron-pyrites is still under investigation.

"The reducing action of organic matters upon soluble sulphates is well seen in the sulphuretted hydrogen which is evolved from the stagnant sea-water in the hold of a ship, and which coats silver exposed to it with a black film of sulphide of silver, and for the same reason discolors white-lead paint. The presence of sulphur in the exhalations from some other decaying matters is well known, and in all these cases a soluble compound of iron will act as a disinfectant, partly by fixing the sulphur as an insoluble sulphide. Silver coins brought from the ancient wreck of a treasure-ship in the Spanish Main were found to be deeply incrusted with sulphide of silver, formed in the ocean's depths by the process just explained, which is one that must go on wherever organic matters and sea-water are present, and atmospheric oxygen excluded.

"The chemical history of iron is peculiar; since it requires reducing matters to bring it into solution, and since it may be precipitated alike by oxidation, and by further reduction provided sulphates are present. The metals, copper, lead, and silver, on the contrary, form compounds more or less soluble in water, from which they are not precipitated by oxygen, but only by reducing agents, which may separate them in some cases in a metallic state, but more frequently as sulphides. The solubility of the salts and oxides of these metals in water is such that they are found in many mineral springs, in the waters that flow from certain mines, and in the ocean itself, the waters of which have been found to contain copper, silver, and lead. Why, then, do not these metals accumulate in the sea, as the salts of soda have done during long ages? The direct agency of organic life comes again into play, precisely as in the case of phosphorus, iodine, and potash. Marine plants, which absorb these from the sea-water, take up at the same time the metals just named, traces of all of which are found in the ashes of sea-weeds. Copper, moreover, is met with in notable quantities in the blood of many marine molluscous animals, to which it may be as necessary as iron is to our own bodies. Indeed, the blood of man, and of the higher animals, appears never to be without traces of copper as well as of iron.

"In the open ocean the waters are constantly aerated, so that soluble sulphides are never formed, and the only way in which these dissolved metals can be removed and converted into sulphides is by fixing them in organisms, either vegetable or animal. These, by their decay in the mud of the bottom, or the lagoons of the shore, generate the sulphides which fix their contained metals in an insoluble form, and thus remove them from the terrestrial circulation.

"It is not, however, in all cases necessary to invoke the direct action of organisms to separate from water the dissolved metals. It often happens that the waters containing these, instead of finding their way to the ocean, flow into lakes or inclosed basins, as in the case of the drainage-waters of an

English copper-mine, which have impregnated the turf of a neighboring bog to such an extent that its ashes have been found a profitable source of copper. Under certain conditions, not yet well understood, this metal is precipitated by organic matters in the metallic state, but if sulphates are present, a sulphide is formed. Thus, in certain mesozoic slates in Bohemia, sulphide of copper is found incrusting the remains of fishes, and in the sandstones of New Jersey we find it penetrating the stems of ancient trees. I have in my possession a portion of a small trunk taken from the mud of a spring in the province of Ontario, in which the yet undecayed wood of the center is seen to be incrusted by hard and brilliant iron pyrites. In like manner the trees found in the New Jersey sandstone became incrusted with copper-sulphide, which, as decay went on, in great part replaced the woody tissue. Similar deposits of sulphides of copper and of iron often took place in basins where the organic matter was present in such a condition or in such quantity as to be entirely decomposed, and to leave no trace of its form, unlike the examples just mentioned. In this way have been formed fahlbands, and beds of pyrites and other ores.

"The fact that such deposits are associated with silver and with gold leads to the conclusion that these metals have obeyed the same laws as iron and copper. It is known that both persalts of iron and soluble sulphides have the power of rendering gold soluble, and its subsequent deposition in the metallic state is then easily understood.

"I have endeavored by a few illustrations to show you by what processes some of the more common metals are dissolved and again separated from their solution in insoluble forms. It now remains to say somewhat of the geological relations of ore-deposits, which are naturally divided into two classes; the first including those which occur in beds, and have been formed contemporaneously with the inclosing earthy sediments. Such are the beds of iron-ores, which often hold embedded shells and other organic remains, and the copper-bearing strata already mentioned, in which the metal must have been deposited during the decay of the animal or plant which it incrusts or replaces. But there are other ore-deposits evidently of more recent formation than the rocky strata which inclose them, which have resulted from a process of infiltration, filling up fissures with the ore, or diffusing it irregularly through the rock. It is not always easy to distinguish between the two classes of deposits. Thus a fissure may in some cases be formed and filled between two sundered beds, from which may result a vein that may be mistaken for an interposed stratum. Again, a bed may be so porous that infiltrating waters may diffuse through it a metallic ore, or a metal, in such a manner as to leave it doubtful whether the process was contemporaneous with the deposition of the bed, or posterior to it. But I wish to speak of deposits which are evidently posterior, and occupy fissures in previously formed strata, constituting true veins. Whether produced by the great movements of the earth's crust, or by the local contraction of the rocks (and both of these causes have in different cases been in operation), such fissures sometimes extend to great lengths and depths; their arrangement and dimensions depending very much on the texture of the rocks which have been subjected to fracture. When a bone in our bodies is broken, nature goes to work to repair the fractured part, and gradually brings to it bony matter, which fills up the little interval, and at length makes the severed parts one again. So when there are fractures in the earth's crust, the circulating waters deposit in the openings mineral matters, which unite the broken portions, and thus make whole again the shattered rocks. Vein-stones are thus formed, and are the work of nature's conservative surgery.

"Water, as we have seen, is a universal solvent, and the matters which it may bring and deposit in the fissures of the earth are very various. There is scarcely a spar or an ore to be met with in the stratified rocks that is not also found in some of these vein-stones, which are often very heterogeneous in composition. In certain veins we find the elements of limestone or of granite, and these often include the gems, such as tourmaline, garnet, topaz, hyacinth, emerald, and sapphire; while others abound in native metals or in metallic oxides or sulphides. The nature of the materials thus deposited depends very much on conditions of temperature and of pressure, which affect the solvent power of the liquid, and still more upon the nature of the adjacent rocks and of the waters permeating them. The chemistry of mineral veins is very complicated. Many of these fissures penetrate to a depth of thousands of feet of the earth's crust, and along the channels thus opened the ascending heated subterranean waters may receive in their course various contributions from the overlying strata. From these additions, and from the diminished solubility resulting from a decrease of pressure, deposits of different minerals are formed upon the walls, and the slow changes in composition are often represented by successive layers of unlike substances. The power of these waters to dissolve and bring from the lower strata their contained metals and spars in probably due in great part to the alkaline carbonates and sulphides which these waters often hold in solution; but the chemical history of the deposition of the ores of iron, lead, copper, silver, tin, and gold, which are found in these veins, demands a lengthened study, and would furnish not less beautiful examples of nature's chemistry than those I have already laid before you.

"The process of filling veins has been going on from the earliest ages; we know of some which were formed before the Cambrian rocks were deposited, while others are still forming, as the observations of Phillips have shown us in Nevada, where hot springs rise to the surface and deposit silica, with metallic ores, which incrusts the walls of the fissures. These thermal waters show that the agencies which in past times gave rise to the rich mineral depósits of our western regions, are still at work there.

"Let us now consider the beneficent results of the process of vein-making. The precious metals, such as silver, are so sparsely distributed, that even the beds rich in the products of decaying sea-weed, which we have supposed to be deposited from the ocean, would contain too little silver to be profitably extracted. But in the course of ages these sediments, deeply buried, are lixiviated by permeating solutions, which dissolve the silver diffused through a vast mass of rock, and subsequently deposit it in some fissure, it may be in strata far above, as a rich silver-ore. This is nature's process of concentration.

"We learn from the history which we have just sketched the important conclusion, that amid all the changes of the face of the globe the economy of nature has remained the same. We are apt, in explaining the appearances of the earth's crust, to refer the formation of ore-beds and veins to some distant and remote period, when conditions very unlike the present prevailed, when great convulsions took place, and mysterious forces were at work. Yet the same chemical and physical laws are now, as then, in operation: in one part dissolving the iron from the sediments and forming ore-beds, in another separating the rarer metals from the ocean's waters; while in still other regions the consolidated and buried sediments are permeated by heated waters, to which they give up their metallic matters, to be subsequently deposited in veins. These forces are always in operation, rearranging the chaotic admixture of elements which results from the constant change and decay around us. The laws which the First Great Cause imposed upon this material universe on the first day are still irresistibly at work fashioning its present order One great design and purpose is seen to bind in necessary harmony the operations of the mineral with those of the vegetable and animal worlds, and to make all of these contribute to that terrestrial circulation which maintains the life of our mother earth.

"While the phenomena of the material world have been looked upon as chemical and physical, it has been customary to speak of those of the organic world as vital. The tendency of modern investigation is, however, to regard the processes of animal and vegetable growth as themselves purely chemical and physical. That this is to a great extent true must be admitted, though I am not prepared to concede that we have in chemical and physical processes the whole secret of organic life. Still we are, in many respects, approximating the phenomena of the organic world to those of the mineral kingdom; and we at the same time learn that these so far interact and depend upon each other that we begin to see a certain truth underlying the notion of those old philosophers who extended to the mineral world the notion of a vital force, which led them to speak of the earth as a great living organism, and to look upon the various changes in its air, its waters, and its rocky depths, as processes belonging to the life of our planet.

"ON IODINE AND GOLD IN SEA-WATER.

"After the above lecture was delivered, appeared the results of the researches of Sonstadt on the iodine in sea-water, which were published in the Chemical News for April 26, May 17, and May 24, 1872. According to him, this element exists in sea-water, under ordinary conditions, as iodate of calcium, to the amount of about one part of the iodate in 250,000 parts of the water. This compound, by decaying organic matter (and by most other reducing agents), is changed to iodine, from which, apparently by the action of carbonic acid, iodine is set free, and may be separated by agitating the water with bisulphide of carbon. The iodine thus liberated from sea-water by the action of dead organic matters, however, slowly decomposes water in presence of carbonate of calcium, and is reconverted into iodate, the oxygen of the air probably intervening to complete the oxidation, since, according to Sonstadt, iodides are readily converted into iodates under these conditions. He finds that the insolubility of the iodides of silver and of copper is so great that by the use of salts of these metals iodine may be separated from sea-water, without concentration, provided the iodate of calcium has first been reduced to iodide. By this property of iodine and its compounds to oxidize and be oxidized in turn, Sonstadt supposes them to perform the important function of consuming the products of organic decay, and so maintaining the salubrity of the ocean's waters. Their action would thus be very similar to that of the oxides of iron, as explained in the lecture.

"Still more recently the same chemist has announced that the sea-water of the British coasts contains in solution, besides silver, an appreciable amount of gold, estimated by him at about one grain to a ton of water. This is separated by the addition of chloride of barium to the water, apparently as an aurate of baryta adhering to the precipitated sulphate, which yields by assay an alloy of about six parts of gold to four of silver. Other ways have been devised by him for separating these metals from their solution in sea-water. The agent which keeps the gold of the sea in a soluble and oxidized condition is, according to Sonstadt, the iodine liberated by the reaction already described. The views maintained by Lieber, Wurtz, Genth, and Selwyn as to the solution and redeposition of gold in modern alluvial deposits, seem to be well-grounded, and we are led to the conclusion that the circulation of this metal in nature is as easily effected as that of iron or of copper. The transfer of certain other elements, such as titanium, chrome, and tin, or at least their accumulation in concentrated forms, appears, on the contrary, to require conditions which are no longer operative, at least at the surface of the earth.

"It should here be noticed, that Professor Henry Wurtz of New York, in a paper read before the American Association for the Advancement of Science in 1866, and published in the Journal of Mining in 1868, expressed the opinion that the ocean waters contain gold, and urged experiments for its detection. According to his calculations, the total amount of gold hitherto extracted from the earth, and estimated at two thousand million dollars, would give only one dollar for two hundred and eighty million tons of sea-water; while from the experiments of Sonstadt it would appear that the same quantity of gold is actually contained in twenty-five tons of water."

APPENDIX III.

[From an unpublished Lecture by Professor Raphael Pumpelly.]

ON THE INFLUENCE OF MARINE LIFE AND CURRENTS IN THE FORMATION OF METALLIFEROUS DEPOSITS.

"The researches of Forchhammer and others have proved the existence in the water of the ocean of the following substances:

"1. Oxygen; 2. Hydrogen; 3. Chlorine; 4. Bromine; 5. Iodine; 6. Fluorine; 7. Sulphur; 8. Phosphorus; 9. Carbon; 10. Nitrogen; 11. Silicium; 12. Boron; 13. Silver; 14. Copper; 15. Lead; 16. Zinc; 17. Cobalt; 18. Nickel; 19. Iron; 20. Manganese; 21. Aluminum; 22. Magnesium; 23. Calcium; 24. Strontium; 25. Barium; 26. Sodium; 27. Kalium; 28. Arsenic.

"This list will unquestionably be largely increased when more extended investigations are made; and it seems probable that all of the elements might be found if we could work upon sufficiently large quantities or apply more delicate processes of analysis.

"The dry land of the earth is undergoing an unceasing mechanical and chemical dissolution, and is being carried slowly but surely through rivulets, creeks, and rivers, and, by the action of glaciers and of the waves of the coasts, into the ocean. Slow as this translocation of matter is, nothing is more certain than that, given the necessary time, every portion of the land now above the level of the sea will find its way into the ocean. And this flow toward the great ultimate receptacle of all things has gone on ever since dry land and water existed. What becomes of all this material? Those substances which are carried oceanward in mechanical suspension, as clay and sand and undissolved lime, are deposited along the coast, and are never carried far from the land except under the influence of the currents of great rivers like the Amazon, for instance; but the waters carry seaward an immense amount of carbonate of lime in solution, besides soluble salts of the other earths, of the alkalies, and metals. Why does not this constant influx of carbonate of lime saturate the sea-water and precipitate the excess to form lime deposits? The water of the high ocean contains only a fraction of the amount of this substance which it is capable of taking up. Bischoff supposes that the mollusca and infusoria of the ocean secrete in shell substance and coral banks carbonate of lime directly from the water, which contains an exceedingly small fraction of one per cent., and thus prevents the accumulation.

"This question brings us to the relation between animal and plant life on the one hand and the mineral world on the other. We shall see that many of the most important processes in nature are directly dependent upon life.

"In the mineral kingdom the elementary substances and their combinations have their histories of development according to laws. In their changes of form and association they run through cycles which are less or greater, uneventful or highly complex, according to the limitations fixed upon them by their relative physical characteristics. The cycles of some, at least, of the elements run into, and are intimately dependent upon, some of those in the organic kingdoms. They form the links between matter and life.

"We will look briefly at the cycles of some of the substances with which marine life stands in a causative relation; for some of them are among the agents of the first importance in the production of mineral deposits. These are carbonic acid, lime, phosphoric acid, fluorine, and sulphur.

"We will restrict ourselves to the simpler circuits they follow in the ocean. In a later lecture I shall have occasion to show that these cycles become, on land, much more complex, and merge into those of many of the substances we shall have to deal with.

"CYCLE OF CARBONIC ACID.

"The sea is charged with free carbonic acid. Its water contains about 9 per cent. or 10 per cent. of CO_2. The amount varies with the cloudiness or clearness of the sky and with the roughness or quiet of the water. The excess is aided in its escape into the atmosphere by the action of the waves.

"Under the influence of light the living plants in the sea, as on land, are able to decompose carbonic acid, the oxygen going off free and the carbon going chiefly to form hydro-carbon compounds in the plant. This is the first and essential step: the decomposition of carbonic acid is effected in nature only through the medium of plant life. It can be restored to its original form only through oxidation, which may take place either through direct combustion with the oxygen absorbed as free gas in the sea-water, or by the deoxidation of substances containing combined oxygen. On the dry land it is chiefly oxide of iron which is deoxidized; in the ocean it is the sulphates, especially that of lime. That portion of the hydrocarbon of plants which finds its way into the system of animals is finally oxidized to carbonic acid in the process of respiration during life and of decay after death.

"But another portion is being constantly withdrawn from circulation in the fixed carbon of coal deposits. Unlike any other of the substances which appear to be the most important in the economy of the coördinated realms of nature, coal is, even from a geological point of view, practically incapable of oxidation without the aid of combustion at a high temperature and in presence of oxygen. While the silicates are subject to decomposition by water containing CO_2, and are even slightly soluble as such in pure water, and are sure to return to combination points from which their component parts may be redistributed, the carbon of coal remains fixed. Were there no way outside of the ordinary routine of nature for restoring this element to its combination with oxygen, we should have before us the sure measure of the future duration of plant life, and consequently of animal life also, on our planet.

"But a remedy has sprung into existence almost within the present century—the combustion of coal by man. It is, perhaps, here more than in any other direction that the actions of man show themselves among the physical forces of the first geological importance, and the progress of a material civilization is justified from an entirely new quarter.

"CYCLE OF LIME.

"Nearly all limestones are organic products. Mohr's theory: sulphate of lime decomposed by plants which have the power, under influence of light, of decomposing carbonic acid and sulphuric acid. Carbonic acid gives up its carbon to form hydro-carbon, and oxygen is emitted free. The sulphuric acid yields its sulphur, which unites with the elements of ammonia and with carbon to form albumen, and the oxygen is also here emitted free. The lime enters as an ash ingredient into the fibre of the plant.

"When the plant is eaten by animals the albumen goes to form the living body of the animal, the hydro-carbons are oxidized in respiration to carbonic acid, and this combines with the lime of the plant-fibre, after the oxidation of the organic portion, to form carbonate of lime, which is, secreted together, an organic substance—conchiolin—in the form of shell or skeleton. The animals which live on plants secrete lime directly; those which live on animals obtain it in the last instance from herbivorous animals. The carbonate of lime thus formed goes in the form of shells into the marine strata, or again we find it constituting extensive coral banks and reefs and the immense deposits of glohigerina lime-mud, which seem to form the bottom of the ocean.

"When elevated these deposits are the coralline limestones and chalk; later, the compact or granular limestones, or, after advanced metamorphism, they form rocks which bear no marks of their calcareous origin, and still less of the part organic life has had in their formation.

"Now begins the retrograde movement; the limestone thus elevated must sooner or later return to the ocean. A part goes oceanward in the mechanically suspended silt of streams, but a large part, also in solution, as bi-carbonate. The waters which filter through the soil carry with them carbonic acid, partly from the atmosphere but especially from the vegetable mould, where the hydro-carbons of dead vegetation are constantly oxidizing to carbonic acid. The water, armed with this powerful agent, dissolves slowly but surely the mightiest beds of limestone and carries it seaward. Here it is decomposed by sulphuric acid, under formation of free carbonic acid and sulphate of lime, and the cycle is ended.

"PHOSPHORIC ACID AND FLUORINE.

"The water of the ocean contains phosphoric acid and fluorine. The first can be determined qualitatively in a half pound of the water; besides this, it can be quantitatively determined in plants which live and grow without touching the bottom, and consequently derive their constituents wholly from the sea-water.

"Fluorine was found by Forchhammer directly in the sea-water. It is present in the boiler incrustations of ocean steamers, and Dana found it in the calcareous corals.

"Although these two substances possess little or no chemical affinity, it is a remarkable fact that they are frequently associated in the mineral kingdom, and so generally, indeed, that where one of them is found the other may be almost confidently looked for. This constant coöccurrence is one of the sign-boards in the path of those who would study the genesis of mineral deposits. The coöccurrence is so general that it cannot be accidental, and the fact that the two elements have so slight a chemical affinity is of itself strongly in favor of believing at the start that the association is due to other than inorganic causes. If we turn to the animal kingdom we find these two elements constantly in company.

"In the ocean, as on the land, it is one of the functions of plant life to store up *phosphoric acid.* According to the many analyses of marine fucoids made by Forchhammer, the ashes of these plants contain something over one per cent. of phosphate of lime. It is from the vegetable kingdom or from herbivorous animals that animals obtain their supply of phosphoric acid. The corals contain a larger percentage than the fucoids, and the higher animals, which have skeletons of bone, contain a still larger amount, as in the ox, the bones of which are more than half phosphate of lime.

"We have seen that even the lower marine animals contain fluorine; whether they derive it from some very minute quantity that may be contained in marine plants or directly from the sea-water is not known; in either event the two elements are brought together through the action of vital forces. As these phosphates of lime form essential constituents, especially of the skeletons, teeth, etc., of the vertebrata, and, in a less degree, of the calcareous portions of the rock-building lower animals, they pass into all submarine in which the remains of mollusca and vertebrata are buried, and they form an essential portion, however small the per centage may be, of the extensive coral reefs and the immense deposits of chalk formed by the globigerina. When these submarine formations are raised to form dry land they become, in time, the various limestones and fossiliferous rocks. The phosphate of lime and fluor calcium offer nearly equal resistance to solution by the same solvents, but they sooner or later move in the endless circuit. We find them concentrated in concretionary deposits of phosphates, or, and still near each other, in a generally associated group of minerals, viz: apatile, fluor-spar, tourmaline, topaz, etc. They are here, again, the mineral kingdom, and they are widely spread through the rocks, though in minute quantities. They occur as essential and as incidental ingredients of minerals in nearly all rocks, including granites and basalts. During the decomposition of these rocks the phosphoric acid and fluorine pass into the soil; the process we have followed in the ocean now being again on land, the vegetation extracts phosphoric acid and probably the fluorine from the earth, and the animals concentrate them more rapidly and to a greater extent from the plants and from herbivorous animals, and from the animals they return to the earth partly in their most soluble combinations, which are leached from the soil and carried to the sea to begin afresh their oceanic cycle.

"SULPHUR.

"There is another cycle which is dependent upon the coöperation of organic matters; I refer to that of sulphur. The exhalations of sulphuretted hydrogen and the deposits of sulphur occupy an important place in economic geology; the association of sulphur with metals will demand our attention in treating of ore deposits. The great source of sulphur lies in the ocean, in the dissolved sulphates of lime and magnesia. The reducing agent is organic matter. We have considered one small cycle which sulphur follows in the decomposition of gypsum by plants in which the sulphuric is reduced, the oxygen escaping and the sulphur passing into albumen and finally returning to the sea as sulphuric acid or as sulphuretted hydrogen, which oxidized to the acid in presence of the air, absorbed in the water, and finally returns to gypsum by decomposing the carbonate of lime brought from the land.

"Another and more direct process is in constant operation. The sea is charged with dead organic matter, which requires oxygen for its decomposition, and this it can obtain only from the absorbed air or from the sulphates. Where the amount of dead organic matter is considerable the decomposition of the sulphates is on a very large scale. The carbon of the organic substance takes the oxygen from the sulphuric acid and from its base and the result is carbonic acid and a sulphide. The sulphide is decomposed by water and carbonic acid to sulphuretted hydrogen and a carbonate.

"The sulphuretted hydrogen thus formed is gradually oxidized to sulphuric acid, and the cycle is closed when it again unites with lime to form gypsum.

"This is the circuit of sulphur in the ocean and on the land. The sulphur may branch off into the cycles of other substances, but it must ultimately return to sulphuric acid. As sulphuretted hydrogen it will precipitate any of the heavy metals that are brought in solution in small amounts by the rivers into the ocean; its existence and career is then bound up in that of the deposits in which it is buried.

"On the land it is exposed to a much more complicated career; the sulphuretted hydrogen formed here, as in the sea, through the reduction of sulphates by organic matter, is liable to be seized upon by the metallic salts and fixed as sulphide; when in time this oxidizes, the sulphate or the free acid formed are exposed to a long series of chemical activities, perhaps to many cycles, before the acid combined with lime again enters the ocean as gypsum.

"Besides those substances which exist in amounts which can be quantitatively determined by analyses, the oceanic fluid contains also a very considerable portion of the other elements, some of which have been found directly in the water, while others, especially among the heavy metals, have been found only in the ashes of marine plants or in the calcareous secretions of marine animals, which could have obtained them only from the water in which they live. It is a remarkable fact, that the very careful researches of Bischoff and Forchhammer and Von Bibra failed to find any trace of most of the heavy metals in sea-water directly, while in the ashes of marine plants which germinate, live, and die entirely independent of any root-hold, and pass their whole existence floating in the water, very appreciable quantities of lead, copper, zinc, nickel, cobalt, and silver were found. We have here the most direct proof that the water of the sea contains extremely minute quantities of metals, and that the vital force of plant life has the power of secreting and concentrating them from the enveloping fluid. It is probable that the lower marine animals either secrete them directly from the sea-water or obtain them in the second instance as they do their lime, from the plants which they consume, although here it is perhaps not susceptible of proof that a part of the metals found in coralline structures, may not have been the result of a precipitation of the minute quantities contained in the water, through the agency of sulphuretted hydrogen created by the reaction of the decaying animal matter upon the dissolved sulphates. It may seem to you at first sight that such inappreciable quantities as are represented by the metals contained in ocean-water are too insignificant to have any bearing upon economic geology; but we are too apt to neglect the value of small quantities and unseen forces, and not to concede to nature the ability to accomplish, on a much grander scale, operations which we are every day conducting.

"It may seem also to be an unimportant fact in geology that marine plants have the power of concentrating metals from the ocean. It would, indeed, be a fact of but little moment if the quantity of the plants floating in the ocean were small; but the extent of oceanic vegetation is immense. The amount of marine animal life far exceeds that of the land; and as this presupposes a corresponding amount of vegetation, without which the animal cannot exist, we have an *a priori* reason for placing a high estimate upon the amount of marine plant life; but, fortunately, we have the proof offered by direct observation. The ocean has immense forests containing a great variety of plant forms. The rocky coasts in all parts of the world support a submarine growth of plants, which, though attached to the bottom, obtain their nourishment from the surrounding water. I can give but a faint idea of the magnitude of this vegetation when I state, that on the coasts in many parts of the world the collecting of these plants, for various purposes, forms a very important branch of industry, giving employment to hundreds of thousands of people. In France alone, about three thousand tons of the *ashes* of certain of these plants are worked yearly for iodine, and in Scotland a very much larger amount. On the Orkneys over twenty thousand people are said to have been employed every summer in collecting and burning kelp for potash and iodine. On the coasts of Japan the amount of sea-weed gathered as an article of food, for consumption at home and in China, is immense.

"The size of some of these plants, especially the *Fucus giganteus*, is comparable in point of length, though not in thickness, with our tallest trees. Cook found no bottom in twenty-four fathoms in places where this giant kelp reached the surface, and there is reason to believe that they extend from two to three hundred feet in length. Darwin compares this submarine growth with the tropical land forests, and considers them more important in size and capacity for supplying nourishment to animals than their continental rivals. But besides this fixed vegetation the sea nourishes a vast amount of floating plants, which live in the ocean or move in its currents and accumulate in its eddies. If you will look at a chart of the world you will see, between longitudes 20° and 65° west from Greenwich, and between the parallels of 20° and 45° of north latitude, a long belt stretching from east to west, with a width of from 12° to 4° or 5°, and marked Sargasso. Similar areas exist in the Pacific Ocean.

"These are the accumulation principally of Sargassum of varieties of fucus, brought by the oceanic currents and left behind them in the great eddies. Maury estimated the area of the Atlantic accumulation to be equal to that of the great Valley of the Mississippi. Humboldt rates it about six times the size of the Germany of his day. Roughly stated, it may be considered as occupying an area of from 700,000 to 800,000 square miles. It was in this mass of floating weed that the sailors of Columbus took fright, fearing that their vessels would become hopelessly entangled. 'The sea was covered with such a quantity of sea-weed that we believed that the ships would run aground for want of water.' It was a serious impediment to the early navigators. 'Laerius passed for fifteen continuous days through one unbroken "meadow," so that he could find no way through for oars.' The Sargasso sea often appears 'substantial enough to walk upon.'

"These eddies of the ocean are the ultimate receptacle of everything that floats. The whole ocean surface is subject to greater or less current movements, and everything that has no root-hold or foot-hold and no power of independent motion comes to rest and decay and sink in these quiet waters. When the sea-weed dies the air vessels which buoy it up burst and the plant sinks.

"When we consider that these currents and eddies must be as old as the Atlantic and Pacific Oceans, and that marine vegetation is even older than animal life upon the globe, it becomes evident that deposits of great superficial extent and of great thickness must have accumulated at the bottom of such parts of the sea, and along the track of the currents.

When geological changes occur which bring the coast line or the mouths of great silt-loaded rivers nearer to these deposits, they may become mingled with argillaceous material; or, if the change has carried the eddy to a distance, they may become wholly buried in purely mechanical deposits, and over which the rock-building animals may form calcareous strata. In other words, these accumulations of dead vegetation may come to form members of the series of stratified rocks. With them are buried the minerals secreted by the plant during its life, and also a considerable amount of phosphate and carbonate of lime, contained in the bodies of the vast animal population, which is known to inhabit the floating wilderness of the Sargasso seas; for these are living worlds, teeming with animals which live on the Sargassum, and are in turn preyed upon by the fierce crustacea and carnivorous fish.

"Thus we have a double concentration: first, the plant concentrates substances from the sea-water; secondly, the currents of the ocean concentrate the plants geographically. It seems to me that we have here made one step forward; that we have found at least one of the causes of the unequal geographical distribution of many deposits of metals.

"Besides the metals, the ash ingredients of these plants contain as much as from three per cent. to twenty per cent. of sulphuric acid, besides lime and baryta. The remains of animals deposited with them contain fluoride of calcium.

"In the presence of organic matter and sulphuric acid the metals must in time be reduced to sulphurets. These deposits contain, then, sulphurets of the metals, and the constituents of three of the four principal varieties of vein-stones, viz: carbonate of lime, sulphate of baryta, and fluoride of calcium, the two last being generally closely connected with metallic deposits.

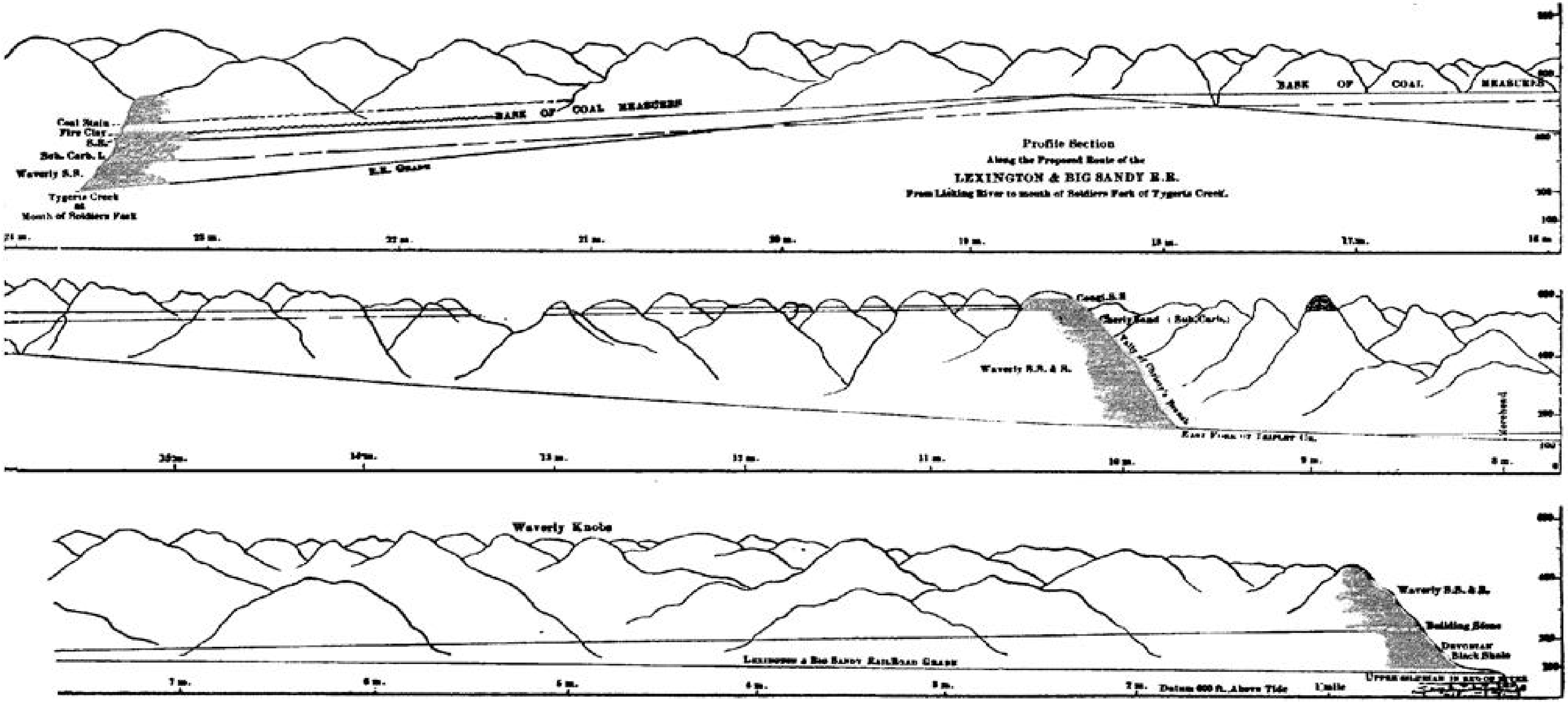
"When these marine accumulations and the accompanying strata are elevated and begin to undergo metamorphism, they contain at least many of the principal metals, as sulphurets, and with these the materials for vein-stones, minutely disseminated through the rock-mass.

"After an advanced metamorphism has either removed the remains of the plants, or after the organic matter has reached that stage of carbonization where it ceases to act vigorously as a reducing agent, it is possible for the next phases of concentration to begin, under which metallic deposits proper are formed, by bringing together within very narrow limits the larger part of the metals diffused in extremely minute quantities through great masses of rock.

"We have seen that the calcareous remains of the lower marine animals also contain appreciable quantities of metals. Bischof was also able to detect the presence of silver in treating only one and one fourth pounds of *Pocillopora alcicornis*, one of the common reef-forming corals. Many of the substances, including metals found in these remains, have not been detected, although looked for in the water of the sea, although it is quite certain that they have been concentrated from it. Here, too, it may seem that we are dealing with very insignificant quantities. Far from it. The rock-masses built up and left by these animals in the form of extensive coral reefs, form now and have formed, through all the geological epochs from the Azoic to the present day, very important portions of the superficial crust of the earth. They, too, contain, besides the carbonate of lime, fluoride of calcium. While the plants required the currents of the ocean to effect a geographical concentration, this process is effected by the corals themselves.

"There is another deposit of far greater extent, the builders of which have not, so far as I am aware, been analyzed to detect the presence of metals. I refer to the present bottom of the ocean. The expeditions sent out to examine the ocean bottom with reference to laying the telegraphic cables, the soundings of the United States Coast Survey, and special expeditions sent out by the British and Swedish Governments, have shown that the floor of the ocean is formed almost wholly of casts of polythalamia, especially of globigerina. According to M. de Portalis, this deposit begins on the American coast in the neighborhood of the hundred fathom contour line, so that practically it is co-extensive with the ocean. Microscopic examinations have shown it to be identical in character with the chalk. To these and to the corals we owe, in all probability, the limestone strata of all ages, and many beds of metamorphic rocks, which have resulted from the metamorphism which has replaced the carbonate of lime by silicates.

"With the disintegration and denudation of the dry land the metalliferous deposits inclosed in the rocks are also destroyed, and their contents are carried in mechanical suspension and in solution toward the sea; and were it not for the presence of sulphuretted hydrogen, which is being constantly formed, the ocean would contain in solution metallic salts to an extent which would seem to be incompatible with the existence of life. It is probable that the metals thus brought into the ocean are almost immediately precipitated as sulphurets and intimately diffused in the coast sediments. Here, then, is another great cycle begun in the sea by the action of vital force in plants and animals, running part of its course on land, returning again to the ocean, where the circuit is closed by an agent which can exist there only through the destruction of that vital force."


Profile Section
Along the Proposed Route of the
LEXINGTON & BIG SANDY R.R.
From Licking River to mouth of Soldiers Fork of Tygerts Creek.

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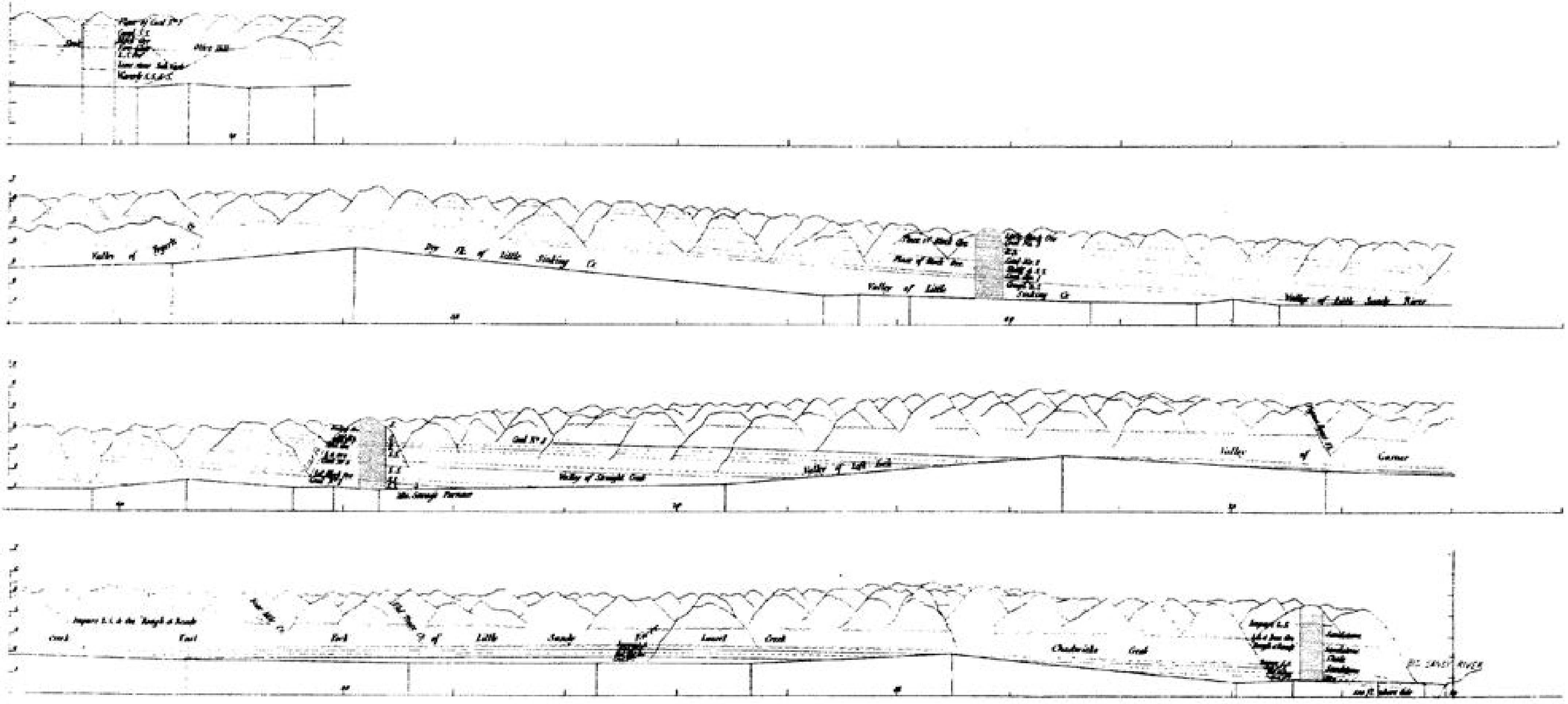
GEOLOGICAL SECTION FROM MT. STERLING TO THE CHATTARAWA OR BIG SANDY RIVER

ON THE PROPOSED LINE OF THE ELISABETHTOWN LEXINGTON AND BIG SANDY RAIL ROAD.

Horizontal Scale 500 Ft. to the Inch. – Vertical Scale 500 Ft. to the Inch.



GEOLOGICAL SECTION FROM MT. STERLING TO THE CHATTARAWA OR BIG SANDY RIVER

ON THE PROPOSED LINE OF THE ELISABETHTOWN LEXINGTON AND BIG SANDY RAIL ROAD.

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