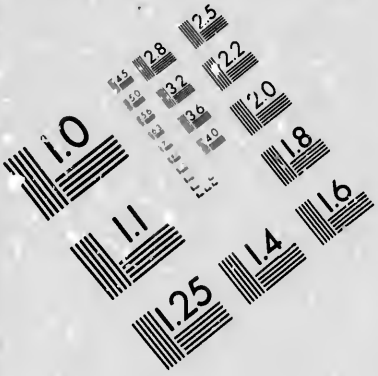

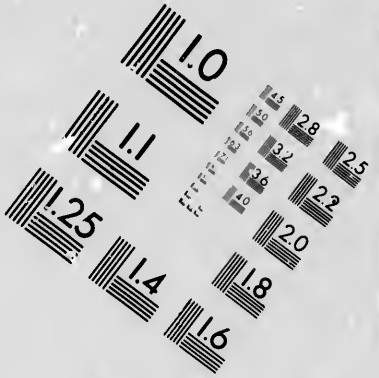

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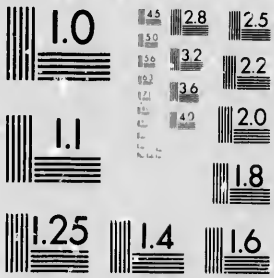

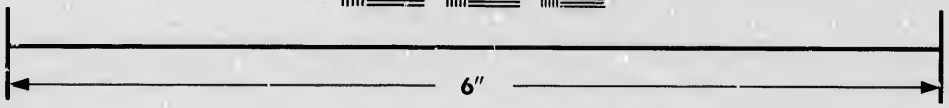

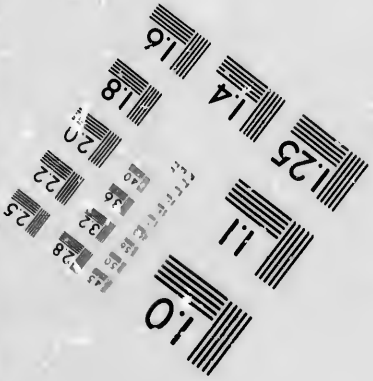

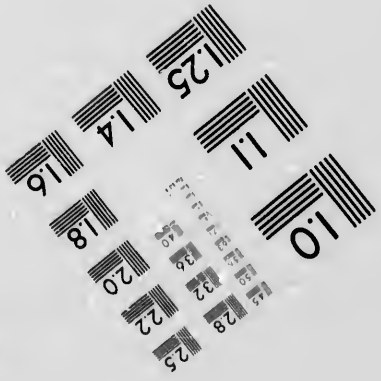

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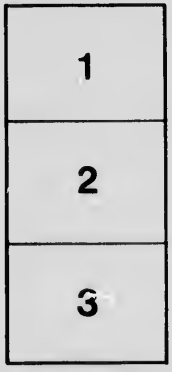

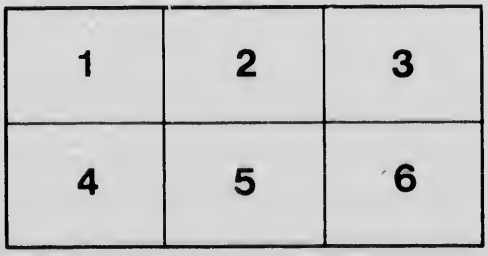

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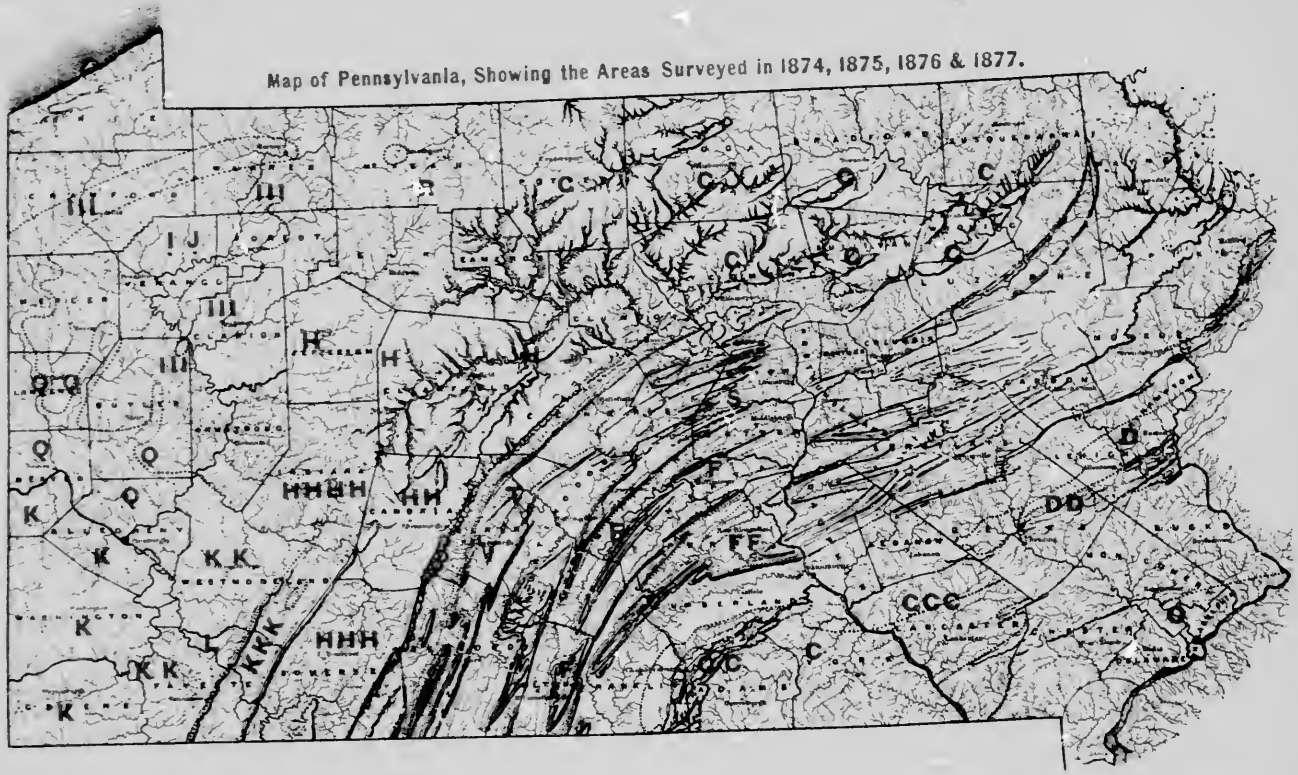
Map of Pennsylvania, Showing the Areas Surveyed in 1874, 1875, 1876 & 1877.

SECOND GEOLOGICAL SURVEY OF PENNSYLVANIA:
1875.

SPECIAL REPORT

ON THE

TRAP DYKES AND AZOIC ROCKS

OF

SOUTHEASTERN PENNSYLVANIA.

BY

T. STERRY HUNT.

PART I.

HISTORICAL INTRODUCTION.

HARRISBURG:
PUBLISHED BY THE BOARD OF COMMISSIONERS
FOR THE SECOND GEOLOGICAL SURVEY.
1878.

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LETTER

BY THE STATE GEOLOGIST.

PHILADELPHIA, *June 14, 1878.*

To the Governor and Honorable Board of Commissioners of the Second Geological Survey of Pennsylvania.

GENTLEMEN: I am happy to present the printed Report which you requested Dr. T. Sterry Hunt—for many years Chemist and Mineralogist to the Geological Survey of Canada, and now Professor of Geology in the Institute of Technology, in Boston,—to prepare.

The resolution of the board is dated August 5, 1875, and specifies the object in view as "a special examination and report on the Trap rocks of Pennsylvania," the Secretary of the Board being requested to communicate with Dr. Hunt. At the meeting of Nov. 4, 1875, the Secretary reported that Dr. Hunt had accepted the task; and the State Geologist reported that Dr. Hunt had already commenced his survey in Southern Pennsylvania, and that it would necessarily involve a study of the Azoic rocks.

The volume in hand will sufficiently attest to this evident necessity.

The survey of the Azoic rocks of Southern and Eastern Pennsylvania has been entrusted to three competent geologists of the regular corps, to wit:

To Professor Frederick Prime Jr. of Lafayette College, Easton, the topographical and geological survey of the Siluro-Cambrian slate and limestone valley of Berks, Lehigh and Northampton counties, including areas of Azoic uplift; together with the Azoic mountains, (and included limestone valleys,) stretching from the Delaware to the Schuylkill

rivers. This elaborate survey has been in progress under Prof. Prime's able direction since the beginning of the survey. The second volume of his reports of progress is about to issue from the press, and his field-party is engaged in finishing the southern border of the mountain-land, including the overlapping edge of the Trias.

To Professor Persifor Frazer Jr. of Philadelphia, was assigned a similar instrumental survey of the Azoic mass of the South Mountain in York, Adams, Franklin and Cumberland counties; including the Siluro-Cambrian limestone contact on the northwestern side, and the Trias contact on the southeastern side, with an enclosed limestone valley. Prof. Frazer's lines however traversed the wide low-lying triangle between the South mountains, the Susquehanna river and the Maryland state-line; occupied by a broad belt of Trias, by two belts of limestone, and a still broader belt of Azoic slates, of unknown relationship. This important and minute survey has been going on since 1874, and is far from completion yet. Prof. Frazer in 1877 continued his personal survey of the York county limestones and Azoic slates and gneisses into and over the whole of Lancaster county, his report of which is nearly ready to go to press. But his field-party continues the slow and laborious work of mapping the South mountains.

To Mr. Charles E. Hall has fallen, in a natural way, as the geologist in charge of the State Museum, the even more difficult task of unraveling the tangled threads of that skein of Azoic gneisses and slates which stretches from the Delaware River at Trenton, across the Schuylkill between Philadelphia and Conshohocken, through Chester and Delaware counties, to the Delaware and Maryland state-lines. Several thousand hand specimens have been collected and arranged in the museum, for study and comparison; and every exposure of rock, however insignificant, is not only represented in the cabinet-series of cross-sections, but located on the map. A long stride has already been made towards the true solution of the problem of our Azoic rocks, and of their relationship to the slate, sandstone and limestone formations which overlie them.

Meanwhile many microscopic and chemical analyses of these enigmatical rocks have been made by Dr. Genth, the Chemist and Mineralogist of the Survey; who has also paid great attention to the species of traps collected, and will continue to make a special study of that subject.

In support of the assiduous studies by these gentlemen of the Azoic rocks in their respective districts, and to further the success upon which they can already congratulate themselves, it was unquestionably desirable to compare their observations and conclusions with those made and reached, by geologists outside of the State, in the Azoic regions of New Jersey, Northern New York, New England, and especially of Canada. No better plan could have been adopted to reach this end than to invite so distinguished a student of Azoic geology as Dr. Hunt to visit those districts of our survey which seemed to correspond with those in the north among which he had spent the best part of his laborious and successful life; and no book could be more useful than one in which he should collate all the known, supposed, and suspected facts of American Azoic geology; with all the accepted conclusions, and proposed hypotheses, published on the subject by the most eminent geologists of the last half century in Europe and America.

We owe therefore a debt of gratitude to Dr. Hunt for this historical monograph, which will supply a deeply felt deficiency in the literature of our science. It is a treasury of notes and suggestions of the greatest value to the geologists of Pennsylvania, and of other States, working in such districts as are occupied at the surface, or are underlaid at moderate depths, by the Cambrian and sub-Cambrian formations; although no final demonstration has been accomplished by the author of those problems of superposition, unconformability, and identification, at which so many geologists are still half despairingly at work. But his opinions of the probable final solutions of these problems will reënforce their own, when they agree, and lead to fruitful discussions when they disagree.

Dr. Hunt's views on one or two points, like that of the relationships of the slates of the great valley, are peculiar

to himself, and are not in accordance with the views of the Pennsylvania geologists either of the First or Second surveys. But it is of real importance to obtain the circumstantial statement of his opinions given in this report. The finished instrumental survey of these slates and underlying magnesian (Siluro-Cambrian) limestones in Blair county, and the rapidly advancing surveys of the same outcrops in Clinton, Mifflin, Cumberland, Dauphin, and Lebanon counties, with the close instrumental surveys at the Schuylkill, Lehigh, and Delaware water-gaps, confirm our opinion of the correctness of the interpretation made by the geologists of the First survey.

It is still somewhat premature to dogmatize about the Taconic system; as it is impossible yet for any competent judge to express a positive opinion respecting the value of such terms as Montalban, Norian, &c., in Pennsylvania; seeing that the closest scrutiny during the last two years has not availed even to make it *certain* whether the gneiss belt *under*lies or *over*lies the mica-slate belt in Bucks, Montgomery, Philadelphia and Chester counties; although Mr. Hall has made it almost certain now that the Edgehill rock lies at one locality unconformably, and in a synclinal, upon the gneiss, and that the Chester-valley limestone, of later age, occupies this same synclinal.

Since Dr. Hunt's observations, made two years ago, Professor Frazer has worked out the important section along the Susquehanna river, and determined the great anticlinal uplift across Lancaster county, with gneiss in its axis, throwing off, on opposite dips to the north and south, many thousands of feet of Azoic slates, all of them older than the Cambrian (?) calcareous slates which underlie the magnesian limestones. And Professor Prime has found graphitic gneiss with limestones in the (Laurentian?) uplift north of Bethlehem. Light seems fast breaking in upon this dark region of our geology.

Respectfully submitted,

J. P. LESLEY.

PREFACE

BY THE AUTHOR.

This volume owes its origin to a request of the Commissioners of the Second Geological Survey of Pennsylvania that the author should prepare a report on the geology of that State with especial reference to the Azoic Rocks, the Trap Dykes and the Iron Ores. The adequate discussion of these several points, as will be seen, involved the consideration of some of the least known and most debated questions in geological science.

The designation of Azoic rocks, as used by the late Prof. H. D. Rogers in his final report on the Geology of Pennsylvania, was restricted to the upper portion of the crystalline schists, occupying a horizon between the uncrystalline paleozoic sediments and that more ancient gneissic series to which he gave the name of Hypozoic. This latter was however by him declared to be, in many cases, so like the intermediate or Azoic series as to render it impossible to distinguish, lithologically, between the two. The united Hypozoic and Azoic rocks constitute the Azoic system of Foster and Whitney, which, according to these geologists,

included all the rocks below the fossiliferous sedimentary strata, and has been shown by subsequent investigations to comprise several distinct stratified terranes.

A large portion of the rock-masses associated with, and in fact forming an integral part of this Azoic system, were, by the writers last named, included in the category of igneous or erupted rocks. Such were the gneisses, the quartzose or petrosilex-porphyries, the greenstones, the serpentines, and the masses of magnetic and specular oxyds of iron. Other, and contemporary writers added to this list, labradorite or hypersthene-rock, together with certain crystalline limestones and quartz-rocks. Later researches have however led most geologists to the conclusion that by far the greater part of these so-called igneous rocks are stratified or indigenous masses, which are not to be confounded with the distinctly intruded exotic rocks, such as the true granites, the trachytes, dolerites, etc.; nor yet with the concretionary veinstones which, like these, traverse the stratified rocks.

It was evidently a question of the first importance in the proposed investigation to draw the lines between the three orders of crystalline rock-masses just defined, and to determine whether a so-called trap-dyke is a foreign mass, which has been injected among previously formed neptunean strata, or is itself an original part of the stratified formation. The same question arises with regard to the deposits of magnetic and specular oxyds of iron, which abound in the crystalline rocks, and, within the last few years, have come to be considered not as intruded but as indigenous masses. The change of views on all these points which has taken place within a generation, constitutes a complete revolution alike in geogeny and in geognosy.

Other, and not less important questions arise in this connection, with regard to the older paleozoic formations and their relations to the crystalline terranes. These relations have been the subject of much misconception, and many contradictory hypotheses, and have moreover important bearings on the problems proposed in this report. To prepare the student for an adequate discussion of all these ques-

tions, it was felt that nothing less than a historical and critical review of the progress of our knowledge of the older rocks of North America would suffice.

The publication of Maclure's map and description, in 1817, marks the beginning of sixty years of great activity in the study of American geology, the chief results of which, so far as they bear on the crystalline and other pre-Silurian formations, it has been the author's object to set forth in Chapters II–V of the present work. The fact that for more than one half of this time he has been a constant laborer in different parts of the field, may help to justify him in attempting the task. He has aimed at as great conciseness and brevity as is consistent with clearness of statement, but trusts that the present sketch may serve as the basis of a more complete and extended history of the Pre-Silurian Rocks of North America, which it is his purpose to prepare.

The succeeding chapters of this report will be devoted to the consideration of the decay of crystalline rocks, and its geological importance, and to the nature and origin of the various deposits of iron-ores. They will be followed by the author's observations on the geology of southeastern Pennsylvania, and the elucidation of many of the questions raised in the introductory chapter. As the temporary absence of the author from the country will retard for some months the completion of the work, it has been thought best to publish separately the first five chapters, which conclude the historical and critical part, so far as regards American stratigraphy. An index will accompany the completed report, and meanwhile the present portion is provided with an analysis of the chapters, which, it is hoped, will help to recommend it to students of American geology.

T. S. H.

Boston, Mass., *June 1, 1878.*

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History of American Pre-Silurian Geology, Continued.

CHAPTER IV.

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CHAPTER V.

HISTORY OF AMERICAN PRE-SILURIAN GEOLOGY, CONCLUDED.

CHAPTER I.

INTRODUCTION.

§ 1. In the month of August, 1875, I was requested by the Commissioners for the Second Geological Survey of Pennsylvania to make certain studies in the eastern part of that State, with especial reference, in the language of Prof. Lesley, the director of the Survey, "*to the trap dykes, the iron ores and the azoic rocks.*" The chemical and mineralogical investigation of many of the trappean rocks of the State was already in the hands of Dr. Genth and Prof. Persifor Frazer, Jun., so that it was evident that the work required of me was rather a study of their geognostical relations. This point of view opened up a very wide range of inquiry, involving the following questions:

1. How far are the so-called trappean rocks, which had been recognized by previous observors, indigenous, and how far are they exotic rocks?

2. What are the relations of such rocks, belonging to the one and the other of these classes, to their enclosing strata?

Inasmuch as there are in the region to be examined undoubted eruptive rocks, which traverse all its stratified formations, and

inasmuch, moreover, as other rocks, by many regarded as eruptive, are found enclosed in the older formations, (the mineral characters of which they are generally supposed to have modified,) it became evident that a proper discussion of the *trappean rocks* would require a review of the geology of the whole region. Add to this the history of the *iron ores*, some of which are commonly believed to have intimate relations with the traps; and, moreover, the history of the so-called *azoic rocks*, and the field presented for my geological investigations becomes a very wide one.

By Azoic rocks are generally understood the whole of the Primary crystalline rocks of pre-paleozoic age, for which the names of Archæan and Eozoic have also been suggested. Rogers, it is true, restricted the name of Azoic to a portion of these Primary rocks, while he designated another portion of them as Hypozoic. I have, however, interpreted the term, as used above by Prof. Lesley, in its usual sense, and shall include under this title the whole of the Primary or Eozoic formations known in Pennsylvania.

§ 2. The region to which my inquiries were directed is that part of the State lying to the south and east of the North or Kittatinny Mountain, and includes, besides the Mesozoic sandstones and the rocks designated by Prof. Henry D. Rogers as the Primal, Auroral and Matinal divisions of the Paleozoic system, a great development of crystalline stratified rocks. These were by him divided into an older Gneissic or Hypozoic series, and an upper Semi-metamorphic or Azoic series, the relations of which to one another and to the Paleozoic system are very intimate, and gave rise to certain ambiguities in the descriptions and the nomenclature as set forth by him in his final report on the geology of Pennsylvania, published in 1858.

§ 3. As regards the distinctions between the Hypozoic and Azoic series, these were declared to be: "First, an obvious and very general difference in the composition of the two sets of strata: secondly, a marked difference in their conditions of metamorphism: and thirdly, and more especially, a striking contrast in the direction and manner of their uplift; the plications and undulations of the less metamorphic series dipping almost invariably south-eastward, while the gneiss, in many

localities, has no symmetrical foldings, but only a broad out crop, dipping to a different quarter. These structural dissimilarities imply essential differences in the direction and date of the crust-movements which lifted and transformed the respective groups, and led the geologists of Pennsylvania and Virginia to a conviction that, over at least many tracts, there would yet be discovered a physical unconformity both in strike and dip. It was not, however, until a relatively late date in the prosecution of the Geological Survey of Pennsylvania that the geologist of that State detected positive evidence of this physical break, and of a lapse of time between the two groups of strata."

§ 4. "We have then in the Atlantic slope, by actual demonstration, but one physical break or horizon of unconformity throughout the immense succession of altered crystalline sedimentary strata and, within this region, but one paleontological horizon—that, namely, of the already discovered dawn of life among the American strata. This latter plane or limit, marking the transition from the non-fossiliferous or Azoic deposits to those containing organic remains, lies within the middle of the Primal series or group of the Pennsylvania survey; that is to say, in the Primal white sandstone, which, even where very vitreous, and abounding in crystalline mineral aggregations, contains its distinctive fossil, the *Scolithus linearis*. The Primal slates, beneath the sandstone and in intimate alternation with it, possess not a vestige of organic life, nor has any such yet been discovered anywhere within the limits of the Atlantic slope, or on the northern or western borders of the great Appalachian basin of North America, either in the Lower Primal slate or in the other Semi-metamorphic grits and schists physically conformable with it, into which the true Paleozoic sequence of our formations, physically, extends downwards."

§ 5. We have, then in the language of Rogers, "two main horizons, sub-dividing the more or less metamorphic strata of the Atlantic slope in three systems or groups; the one, a physical break or interruption in the original deposition of the masses; the other, a life-limit or plane, denoting the first advent, so far as yet discovered, of organic beings. As these two planes are not coincident, but include between them a thick group of

sedimentary rocks separated from the lower, physically, and from the upper, ontologically," the author was led "to employ a classification which recognizes a three-fold division of all these lower strata." These three groups he defined to be the *Hypozoic* rocks, or those beneath any life-bearing strata; the *Azoic*, or those destitute of any discovered relics of life; and the *Paleozoic*, containing the remains of ancient life. (See the Geology of Pennsylvania, 1858, vol. I, pages 62-64.)

§ 6. In addition to the relation of continuity already asserted between the Azoic and Paleozoic groups, we are farther told, in the chapter just quoted, that the "Azoic or talco-micaceous group is a genuine downward extension of the Primal Paleozoic series;" while in a succeeding chapter, the whole of the Azoic series is expressly included in the Paleozoic system, of which it constitutes the lower portions. In the preceding extracts, the Azoic rocks are spoken of as comprising the Lower Primal slate, and a group of Semi-metamorphic grits and schists physically conformable with it; but, farther on in the pages of Rogers, the latter alone are distinguished by the name of Azoic, under the head of the Paleozoic system.

§ 7. The Appalachian Paleozoic strata of Pennsylvania, as defined by our author, are said to be, in ascending order, as follows:

"PRIMAL CRYSTALLINE SCHISTS (*or Azoic Group.*)—A very thick and widely diffused group of semi-crystalline strata, indurated clay-slates, talcose, micaceous and hornblendic schists and gray silicious grits, without visible fossils, but in close physical relations with the overlying fossiliferous Primal rocks, and apparently a portion of the Paleozoic system."

To this division succeeds four members, described as portions of the *Primal Series*, namely:

"PRIMAL CONGLOMERATE.—A heterogeneous conglomerate composed of quartzose, feldspathic and other pebbles, included in a silicious or talco-silicious cement. This rock does not appear in Pennsylvania, but is largely developed in Virginia and in Tennessee, where it has a thickness of 150 feet. This formation, and the preceding, seem to lie below the lowest ascertained fossiliferous horizon."

"PRIMAL OLDER SLATE.—A sandy slate of a brown or greenish-gray color, containing much feldspathic and talcose matter. It has hitherto disclosed no fossils. The thickness of this rock has not been ascertained in Pennsylvania, the beds being too much folded. In Virginia it is 1,200 feet thick."

"PRIMAL WHITE SANDSTONE.—A compact, fine-grained white and yellowish vitreous sandstone, containing specks of kaolin. The stratum is distinguished by a cylindrical stem-like fossil, the *Scolithus linearis*, which crosses the beds in a perpendicular direction. Probable thickness about 300 feet."

"PRIMAL UPPER SLATE.—A greenish blue and brownish talco-argillaceous slate, very soft and shaly; its only fossil a peculiar fucoid. It is probably about 700 feet in Pennsylvania."

§ 8. To these succeed the *Auroral Series*, consisting of two members, which are, in ascending order:

"AURORAL CALCAREOUS SANDSTONE.—A coarse gray calcareous sandstone, containing drusy cavities enclosing crystals of quartz and calcareous spar. Within the limits of Pennsylvania this occurs chiefly in Northampton, Centre and Huntingdon counties. It is about sixty feet at Easton."

"AURORAL MAGNESIAN LIMESTONE.—A light blue and bluish-gray massive limestone, containing generally from ten to thirty-five per cent of carbonate of magnesia. In the southwestern part of Pennsylvania it contains thick beds of chert. Its thickness is from 2,500 to 5,500 feet."

§ 9. Of these divisions the Primal white sandstone was by Rogers regarded as the equivalent of the Potsdam of the New York series; and the lower and upper members of the Auroral, respectively, as the representatives of the Calciferous sandrock, and the united Chazy and Black River limestones of New York.

The Auroral is followed in ascending order by the *Matinal Series*, in three divisions, namely: the Matinal argillaceous limestone, the Matinal black slate, and the Matinal shale; supposed to be equivalents respectively of the Trenton limestone, the Utica slate, and the so-called Hudson River shales of New York. (Ibid, I, page 104.)

§ 10. Crystalline characters were not, however, according to Rogers, supposed to be confined to the Hypozoic and the Azoic

or Lower Primal strata. The Primal white sandstone and the Upper Primal slates, as well as the Auroral and Matinal series, in various localities, are described as being more or less crystalline in form, from so-called metamorphic action; which is even supposed by Rogers to have changed the Mesozoic, in some places, into a crystalline rock. The whole of the Primal strata below the white sandstone are elsewhere described as alternations of talcoid silicious slate, talco-micaceous slate and quartzose micaceous rock, usually schistose, besides other strata which are nearly pure clay-slate. Greenish talcose slates are, moreover, said to be associated both with the white massive limestone and the blue limestone of the Auroral series.

§ 11. The larger part of the crystalline rocks of the State are by Rogers referred to the Gneissic or Hypozoic series, although we are told that near the Susquehanna it is difficult to distinguish the silicious talco-micaceous Primal from the more micaceous beds of the Hypozoic. Elsewhere it is declared that where these Lower Primal or Azoic strata "display their maximum amount of crystalline structure or metamorphism, the members of the two groups often simulate each other so closely, and indeed are so identical in mineral aspect and structure, as to baffle all attempts at distinguishing them lithologically; nevertheless it will appear from the evidence embodied in the sections illustrating this country that they are distinct systems, occupying separate zones, susceptible of delineation in the geological map." (Ibid. I, page 66.)

§ 12. He defined three areas or districts of the Gneissic or Hypozoic series in the State of Pennsylvania. The Northern district, being the South Mountain belt, is a prolongation of the Highlands of the Hudson and of New Jersey, which crossing the Delaware below Easton, extends to Reading on the Schuylkill, stretching along the north side of the Mesozoic sandstone belt. The Middle gneissic district extends from near Valley Forge on the Schuylkill, westward into Lancaster county, and includes the Welsh Mountain, between the Mesozoic on the north and the limestone valley of Chester county on the south. The third or Southern district is that extending from the Delaware at Trenton to the Susquehanna south of the State line, and lies wholly south of the limestone valley of Chester and

Montgomery counties, except when the gneiss passes around the east end of the limestone, and lies between it and the southern border of the Mesozoic for a little distance near the eastern corner of the last named county. This Southern gneissic district, in the words of Rogers, "breaks off to the west of the Brandywine river in a succession of narrow tongues. Near the State line of Delaware it sends forth, however, through the south-east corner of Chester county, a continuous and widening belt to the Susquehanna." To the "west of the Brandywine the gneissic rocks sink under the altered Primal strata in a succession of anticlinal fingers on slender promontories." The line of demarkation between these two "series is not, however, a simple one, but is intricately looped in consequence of numerous nearly parallel anticlinal foldings of the strata, sending promontories or fingers of the older rocks within the area of the newer or Semi-metamorphic to the west of their average boundary." (Ibid I, pages 65, 66, 67.)

To the west of this irregular boundary, the whole of the crystalline rocks, which, on both sides of the Susquehanna, extend to the south of the limestone valley of Lancaster county as far as the Maryland line—where through the narrowing of this valley they are brought to the Mesozoic—are represented by Rogers, both in the report and in the geological map, as "Primal altered," with some areas of "Auroral altered."

§ 13. Still farther west, and beyond the Mesozoic, is a large and important mountain area, the northern extension of the Blue Ridge, stretching nearly to the Susquehanna, which is also described by Rogers as "Primal altered" (Ibid. I, page 204.) This, however, in the geological map, is designated as unaltered "Primal." The same is true of some small areas of crystalline slates which appear in the midst of the Auroral limestone near the Susquehanna, to the south-east of the Mesozoic. In calling attention to this discrepancy between the map and the text, I wish to point to another of considerable importance. It will be found, (at least in the copy of the geological map of Pennsylvania before me,) that the Gneissic series in the the legend is represented by a diagonally-lined pink color, which however, on the map, is confined to the Southern district; the Middle and Northern gneissic districts being of a pink color, but unlined.

Inasmuch as Rogers refers the whole three to the same series, there is evidently an error on the part of the cartographer. It seems probable the unlined pink of the districts last mentioned was intended to represent the gneiss. The student of the map will also bear in mind that the areas designated as "Primal," near York, and west of the Mesozoic, and colored a pale yellow, without lines, should, in conformity with the text of Rogers, receive that color which, according to the legend, belongs to the "Primal altered." It may also be observed that the diagonally-lined pale yellow, said in the legend to represent Primal roofing-slates, does not appear upon the geological map.

§ 14. The characters of the three gnesssic district are described with some detail by Rogers, who shows that the rocks of the Northern and Middle districts are very unlike those of the Southern. They consist, according to him, of coarse gneisses, resembling granite, but distinctly stratified, often made up chiefly of quartz and feldspar, frequently hornblendic, and abounding in magnetic iron ore, but rarely containing mica. He also notes the rarity of micaceous, talcose or chloritic rocks, which abound in the Southern district. The Middle district presents some small exposures of highly crystalline limestone with graphite; and the Northern one, near Easton, also exhibits beds of serpentine, with some crystalline carbonate of lime, accompanied with tremolite, light colored pyroxene, brown tourmaline, graphite, and, as I have observed, with large crystals of magnesian mica. The mineralogical and lithological characters of these rocks are similar to those met with in the Highland range in New York and New Jersey, of which this is a continuation; and it was after a careful consideration of all these circumstances that the geological survey of Canada, in the map of eastern North America, published in 1866, represented both the Northern and the Middle gneissic districts of Pennsylvania as belonging to the Laurentian series; to which the gneisses of the Highland range and the Adirondacks had already been referred.

§ 15. The geological structure of these two gneissic regions in Pennsylvania was described by Rogers as presenting a series of closely appressed folds, most clearly seen in the South Mountain,

of which he says, "It will be seen that from one end of the range to the other the gneiss, and the older Appalachian strata in contact with it, are bent into a series of folded or inverted flexures; that is to say, having the strata in the north leg of each anticlinal turned over, and dipping steeply to the south, or rather to the south-east, in accordance with the law so universal throughout our whole Appalachian chain. Near the Delaware, as shown both in the general and the local sections, there are three distinct ridges of the gneiss, separated by two synclinal troughs of the Auroral limestone. Here the entire breadth of the chain is almost seven and a half miles. At the eastern corner of Berks county the breadth is about six miles. Here they (the ridges) consist almost exclusively of the gneissic rocks. Near the Schuylkill, the whole belt is much contracted, consisting chiefly of the spurs of the Neversink mountains, and the ridges are composed almost exclusively of the Primal white sandstone in an altered and much indurated state." (Geol. Penn. II, page 94.) The above structure is shown in numerous sections given by Rogers.

§ 16. In further illustration of the inversion of the strata our author remarks that along the southern side of the great limestone valley, near the Lehigh, the dip of the limestone is, in very many places, to the southward, or towards the gneissic belt, sometimes at an angle of 60°. He adds: "The existence of a steep southern dip along the south side of this valley is in strict analogy with the position of the rocks generally in the valleys of the whole South Mountain chain, and implies an overtilting of the strata to the north. This folding of the beds upon themselves in the synclinal axis of our first great mountain, though highly curious, is a prevailing feature from Vermont to Tennessee." (5th Annual Report, page 25.)

§ 17. We have next to consider the gneissic rocks of the Southern district, the difference between which and the Northern one (setting aside for the present that of the Middle district, declared to be similar to the Northern) is referred to by Rogers as "an essential want of correspondence between the two regions, in the gneiss itself," and as a "marked difference in the composition of the predominant rock of the two gneissic ranges, which must be ascribed to an original difference in the

chemical nature of the strata." This Southern district moreover presents in its different parts such dissimilarities that Rogers was led to divide it into three longitudinal belts, distinguished by mineralogical and lithological characters. The importance which I ascribe to these three divisions is such that I condense from the pages of Prof. Rogers the following descriptions (Geol. Penn. I, pages 64–104.).

§ 18. The southern division or group of the Southern gneissic district is that which is seen on the Schuylkill from Gray's Ferry to the upper end of Manayunk, and includes the region of Philadelphia and Germantown. Of its gneissic rocks, the most common or typical variety of all is a gray, bluish, rather finely laminated mixture of quartz, feldspar and mica; the quartz, for the most part, white or transparent, the feldspar usually white, and the mica generally black or dark brown, and in small plates. This rock occasionally includes small garnets.

Next in frequency to this is a dark bluish-gray, sometimes greenish-black gneiss, composed of hornblende and quartz, sometimes with a little feldspar; the hornblende always greatly predominating. This rock is usually very fine-grained and thinly bedded.

A third common variety in this group is a micaceous quartz rock, generally of a light gray color. Some beds, from a predominance of finely granular quartz, and a subordinate amount of disseminated mica, have the characters of a whetstone. A much coarser kind of gray micaceous gneiss, consisting of a predominance of rather large flakes of mica, with a subordinate quantity of feldspar and quartz, occurs interstratified with all these other species, as a very usual transition-variety between the ordinary gray gneiss and the highly micaceous kinds, which approach mica-slate. It is very usual to find the typical gneiss alternating with the hornblendic species, and both of these alternating with the quartzo-micaceous variety. Interstratified among these varieties of gneiss are beds more or less thick, so abounding in mica as to be entitled to the name of mica-slate.

Occasional beds of the typical feldspathic gneiss are made porphyritic by the presence of more or less insulated segregations of crystalline feldspar, the longer axes of which generally lie parallel to the lamination of the rock. Garnet in small

isolated crystals is common in these rocks, especially in the more micaceous varieties, besides staurolite, cyanite and rutile.

§ 19. The stratified rocks of this Philadelphia group, according to Rogers, enclose various "unstratified or true igneous rocks" including "a peculiar feldspathic *syenite* (a somewhat hornblendic granite) in thick dykes, also a white coarse-grained *granite*, consisting of feldspar and quartz in tortuous and sometimes ramifying veins, *greenstone* and other forms of *trap-rock* in dykes, and also quartz, chromiferous iron ore and other minerals, occurring singly or associated in the shape of elongated thin dykes or narrow veins. To these should perhaps be added some of the masses of serpentine, for the unstratified character of these last named is no longer doubtful."

§ 20. The middle division or group of this Southern gneissic district, where it appears on the Schuylkill, is described by our author as very similar to the southern one, and as consisting of an alternation of four principal varieties of rock. The most abundant is a very micaceous and garnetiferous gneiss, including feldspar and quartz, and having a waved, twisted or undulating lamination, due to the fact that the crystalline plates of mica, displaced by the grains of quartz, are often arranged obliquely to the bedding of the rock. The next most common variety is described as consisting almost entirely of this wavy mica. The rock however graduates into the more micaceous sorts of gneiss by a greater or less admixture of finely granular crystalline quartz, feldspar and hornblende. The southern half of this middle group consists of an alternation of these two varieties of micaceous gneiss, with beds of a thinly laminated hornblendic gneiss; which may sometimes rather be called a hornblende-slate.

§ 21. The northern half of the group consists largely of a fourth variety, described as a gray, fine-grained mixture of granular quartz and minutely crystalline scales of mica, the former predominating and constituting a kind of whetstone. This rock breaks readily into long narrow masses, with smooth sides and ragged extremities, like half-decayed fibrous wood. On its southern side, this rock, which occupies a considerable breadth, is said to alternate with the coarse mica-slates, and on

the north with greenish talcose slates, which, with serpentines and steatite, mark the summit of the middle group of these gneissic rocks, as defined by Rogers. This steatitic range is described as extending from near Chestnut Hill to about a mile west of Merion Square, gradually widening from a narrow belt on the Wissahickon to one-eighth of a mile on the Schuylkill, and to nearly four times that breadth two miles farther westward; beyond which it is said to divide into two branches, which cross Mill creek three-eighths of a mile asunder, and thin out beyond. (4th Ann. Report, page 17.)

§ 23. The third or northern division of the rocks of the Southern gneissic district is described by Rogers as consisting, first, of a massive feldspathic gneiss, often porphyritic, some of it micaceous, and some resembling stratified syenite; and, secondly, of a dark hard hornblendic gneiss, thinly laminated and strongly banded. It is farther described as marked by the prevailingly massive character of its bedding, its large excess of feldspar, and comparative deficiency of quartz, hornblende and mica, which latter mineral is generally black and in very minute scales.

The gneiss of this northern division, near the Neshaminy in Bucks county, contains a small bed of crystalline limestone, accompanied by pyroxene, hornblende, tabular-spar and graphite; which latter mineral was at one time mined in the vicinity. (Ibid, page 14.)

§ 23. The most remarkable feature of this Southern gneissic district is, according to Rogers, the northern dip in the strata, "which prevails all along the Schuylkill, with very few local and trivial exceptions, until we approach the upper or northern side of the third or northern belt, where the rocks are, for the first time, for any considerable width of outcrop, folded and lifted into a generally almost perpendicular dip." The ordinary or average angle of inclination of the strata in the greater portion of the district may be stated to vary between 30° and 50°; the prevailing direction of dip being somewhere between N. 20° E. and N. 30° E., and the undulations and contortions rare and insignificant. In some few cases they attain, for short distances, dips approaching to the vertical, as at Fairmount, where

"the strata are traversed by numerous conspicuous joints, presenting at a little distance a deceptive appearance of a nearly horizontal stratification, in thick and almost parallel beds. This is not to be confounded with the genuine stratification or grain of the rock, as marked by the structural distribution of mica and other minerals."

§ 24. This predominant northern dip is preserved across the southern and middle divisions of the Southern gneissic district until we reach the vicinity of the steatite belt, where for the first time the rocks "present a succession of synclinal and anticlinal undulations." In this division of the section the inclination of the strata, still to a large extent towards the north, is at all angles from 30° up to 70°. It is worthy of note that the steatite bed itself gives evidence of a synclinal wave in the dip, for the talc-slates and mica-slates to the south of it, for several hundred yards, dip steadily towards the north at an angle of about 30°, while those of the northern side of the quarry show a steeper inclination to the south. To the north of the steatite range the northern dip is quickly resumed, and in this part of the mica-slate belt, both on the Schuylkill and the Wissahickon, the dip is steeply towards the north.

§ 25. "Entering now the northern division of the district, with its harder feldspathic gneiss, we encounter the most irregularly dipping or undulating portion of the whole gneissic zone. Approaching the quarries of blue porphyroidal gneiss, at the lower limit of this tract, we meet with a steeply compressed anticlinal axis in the strata, marked by a strong dyke of syenitic granite. Here the south dips are 70°, while the north ones vary from 45° to 55°. Passing the quarries, we immediately encounter a wide space of more than a fourth of a mile, in which the rocks are almost horizontal, and towards the northern edge of this we perceive an axis, or turn in the dip, making a broad, regular synclinal or basin. From the northern edge of this trough to the upper limit of the whole gneiss formation, the gneiss is closely folded and compressed into very steep or nearly perpendicular dips, with numerous short plicatures.

§ 26. "If now," says Prof. Rogers, "we review these interesting features in the structure of this broad zone of gneiss, we

can hardly resist the conclusion that in the three belts passed over by our section, there are really but two groups of rocks, a lower and a higher, and thus the entire zone, viewed broadly, constitutes but one synclinal wave or basin; the harder feldspathic and hornblendic rocks dipping northward throughout the whole southern belt or outcrop, and reappearing in steep and multiplied contortions on the other side of the trough; the upper and more micaceous group of rocks filling the synclinal centre of the trough, and compressed into the lesser foldings which it exhibits, by the lateral force of the wide undulation within which it has been caught and folded."

§ 27. The northern belt of harder gneiss rocks has a breadth of about half a mile in width on the Schuylkill, but runs to a point before reaching the valley of the Wissahickon, only two and a-half miles to the eastward, being overlapped obliquely by the margin of Paleozoic rocks; but it broadens to the westward, until at Darby creek it has a breadth of four miles.

§ 28. This gneissic belt on the Schuylkill is limited to the north by a band of newer strata, defined by Rogers as Primal and Auroral in an altered condition, which constitute a broad belt exposed for some miles across the strike, forming the Montgomery valley, and are overlaid to the north-west by the Mesozoic sandstones. The greater part of this breadth is occupied by limestone, but along the southern border, immediately adjoining the gneiss, are some crystalline strata described by Rogers as altered Primal, and as consisting, at the base, of what he called the semi-porphyroidal group, a thinly laminated hornblendic gneiss, having a maximum thickness of 300 feet, and overlaid by a band of about 200 feet of talcose and micaceous slate, holding garnets. To this succeeds a white quartzose rock containing feldspar, tourmaline and mica, regarded by him as constituting the third member of the Primal series, and from 100 to 300 feet in thickness. These strata are described and figured by Rogers in sections on pages 156, 164, 165, vol. I, Geology of Pennsylvania, where they are represented as nearly or quite vertical in attitude along the northern side of the gneiss, and as passing northward, in some cases after certain undulations, beneath the Auroral limestones. This broad band of Primal and Auroral rocks does not extend much

to the eastward of the Schuylkill; but to the north of a narrow belt, represented as Primal, stretching eastward to the Delaware just below Trenton, there extends the whole distance along the southern border of the Mesozoic a range of gneiss, regarded by Rogers as identical with that which, upon the Schuylkill, forms the northern division of the Southern gneissic district. At the falls of the Delaware, at Trenton, according to him, the rock is a dark hornblendic gneiss, dipping steeply south-south-east.

§ 29. We have seen that our author (§ 26) looks upon the whole of this Southern gneissic region as made up of two groups of strata, a lower and more feldspathic series, appearing on the two sides of the basin, and a newer and more micaceous series, occupying the centre of the synclinal. It might be supposed that these two divisions correspond respectively to the Hypozoic and Azoic series of the author, but the whole succession is described under the head of the older crystalline Gneissic strata, or the Hypozoic series; which is elsewhere said to "consist of true gneiss in all its varieties, quartzose, feldspathic, micaceous and hornblendic, with fully developed or typical mica-schist, talc-schist, chlorite-schist and the other crystalline schists usually classed with the genuine or older (Hypozoic) gneiss." (Vol. II, p. 744.)

§ 30. With regard to the belt of magnesian rocks in the gneissic region of the Schuylkill, he says: "Viewing the steatite as a stratified rock of the mica-slate group, we may reasonably regard it as having been metamorphosed to its present condition and structure by infusion of magnesian matter from the dyke of serpentine, which everywhere adjoins it." (Vol. I, p. 72.) Elsewhere he describes a similar belt of rocks, a little farther to the west, as comprising both "true injected serpentine and serpentinous steatitic talc-schist."

The reader is, however, soon after perplexed to find that the serpentines and steatites of the Schuylkill, and indeed of all the region south of the limestone valley of Montgomery and Chester counties, are described in detail at the end of the chapter on the Primal rocks (Vol. I, pp. 167–172,); leaving it to be inferred, though nowhere distinctly stated, that these are, in some way, related to the Lower Primal (which we have seen to be

synonymous in the nomenclature of Rogers with the Azoic,) rather than to the Hypozoic series.

§ 31. It may, however, be noted that of the serpentine areas represented on his geological map, one, that of the Schuylkill, is placed wholly within the Hypozoic, and another, that of Texas near the Susquehanna, in the Azoic or Primal. Those of South Valley Hill, of the Paoli, as well as the serpentine belt along the Maryland state-line, are each described as bounded to the southward by massive gneissic rocks, which, in the case of the last named, appear to be unconformable in dip with the serpentine. To the northward, the last two belts are said to be bounded by talcose or micaceous and argillaceous slates, including the roofing-slates of Peach Bottom, regarded as Lower Primal. In the case of the serpentine and steatitic belt of South Valley Hill, the gneiss is again repeated, separating it from a limestone valley to the north. The Unionville serpentine region is described as being wholly in the midst of micaceous and talcose schists. (Vol. I, pp. 167–172.)

§ 32. In explanation of this it must be remembered that all the true serpentines were looked upon by Rogers as intruded igneous masses, the eruption of which was accompanied by an infusion of magnesian matter, which had changed into talcose and serpentinous rocks, the micaceous schists, both of the Azoic and Hypozoic series. The more micaceous portions of the Hypozoic are, moreover, declared to resemble so closely the micaceous schists of the Azoic "in mineral aspect and structure as to baffle all attempts at distinguishing them lithologically."

§ 33. This point is further discussed near the close of our author's second volume, where, in a sketch of the geology of the United States, after referring to the labors of the Canada Geological Survey, which had, in 1847–1852, pointed out the existence of a series of crystalline schists intermediate between the ancient gneissic system and the Paleozoic series, he refers to the investigations of Prof. William B. Rogers in Virginia, who had, as early as 1839, recognized a similar series east of the Blue Ridge in Virginia. These rocks, extending along the "Atlantic slope of the southern states," were said to consist "of various coarse talcoid and chloritic schists, semi-porphyritic arenaceous

grits and conglomerates, and jaspery and plumbaginous slates, all penetrated extensively by metalliferous veins and dykes, particularly of gold-bearing quartz, and by dykes of porphyritic greenstone, epidote and other older plutonic rocks. * * * Nevertheless it is impossible in the present early stage * * * to define with any accuracy, over large spaces of country, *the upper and lower limits* of this more or less independent semi-metamorphic system, and it is especially difficult, at present, to separate it from the overlying genuine Paleozoic formations, into which, indeed, this series may probably graduate, in many districts, without any physical break at all. The Azoic sediments were succeeded by the Paleozoic, in some quarters apparently with, in some without, the interruption of a disturbance of levels, with interruptions amounting to mechanical unconformity."

§ 34. "In view of this uncertainty respecting the true limits of the older groups, no attempt is here made to define in the regions of the metamorphic rocks more than two systems—the genuine or older gneissic, and the later or semi-metamorphic strata; the latter including both the supposed middle series or true Azoic strata, and the proper Paleozoic formations altered in type. This merging of the latter two groups under one series is made indispensable by the absolute impossibility of ascertaining at present the true base of the Paleozoic system; for the history of geology forbids us to believe that research has yet detected the actual horizon of the dawn of animal and vegetable life upon our globe." (Vol. II, page 745.)

§ 35. The crystalline condition which characterizes the intermediate or so-called Azoic series, in some cases, according to Rogers, extends upward, embracing all the members of the Paleozoic series mentioned in §§7–9. We are told that the Primal white sandstone is occasionally converted into a vitreous quartzite, and at other times into a "stratified feldspar rock," while "the limestones at the passage of the Primal into the Auroral," or as elsewhere defined, at "the alternations of Primal slate and Auroral limestone, are converted into crystalline dolomite or marble, with seams and partings of crystalline scaly talc." The Auroral limestone is said to become "a white and

mottled marble, with semi-plumbaginous laminæ"; while the gray sandstone of the Matinal series becomes "a highly indurated semi-porphyritic grit," and the Matinal shale "a semi-crystalline clay-slate, partially talcose or micaceous."

§ 36. In illustration of these statements we may cite the account given by Rogers of an area of crystalline rocks met with in the South Mountain, to the south of the Susquehanna river. The strata are described as chiefly of three classes; one being a group of chloritic, micaceous and talcose slates, with hard green rocks abounding in epidote and quartz, sometimes with asbestus, and containing occasionally small portions of copper ores and of native copper. A second class includes several varieties of what is described as a reddish jaspery rock; elsewhere called a highly altered jaspery slate, red or reddish-gray in color, and sometimes holding specks of red feldspar and small veins of epidote. In addition to these is a third class, of granular quartzites or sandstones, sometimes described as talcose and quartzose conglomerates.

§ 37. These rocks, which rise in a series of parallel ridges on the south-eastern border of the great valley of Auroral limestone, were by Rogers regarded as members of the Primal series; the reddish jaspery strata being the Primal upper slates, "greatly modified in texture by the intrusion of quartz, and by other igneous action;" intrusive greenstones and traps being mentioned as occurring in the series. Elsewhere we have seen that the Primal white sandstone itself was supposed to become, by alteration, a feldspar-rock. To the Primal lower slates are referred at least a portion of the greenish chloritic and epidotic rocks of the region; while the sandstones with talcose slates are supposed to represent the Primal white sandstone.

§ 38. These strata present, with some exceptions, dips to the south-east, often at high angles, and the structure of the region is described by Rogers as a series of folds, with inverted dips. In illustration of this we are told that on the north-west side of the mountain the Primal upper slates are found dipping southward, and overlaid by the Primal sandstone; while from beneath this, on the crests of the anticlinals, appear the greenish epidotic strata of the Primal lower slates. Portions

of the Auroral limestone are found, in one or more places, in the synclinal folds of this mountain-belt; and in one locality are associated with the hydrous iron ore which usually accompanies this limestone series. (Vol. I., pp. 202–207.)

§ 39. It will be observed that under the head of eruptive or igneous rocks Rogers includes the so-called dykes of serpentine; and, moreover, that the greenstones and epidotic rocks, which are abundant in many parts of the schistose crystalline strata, are spoken of as eruptive or plutonic in character; while even the quartz veins found cutting the strata were regarded as of igneous origin. It is moreover suggested that the Primal sandstone itself may have been derived "from the great dykes and veins of auriferous quartz," supposed to have issued "in a melted condition through rents and fissures in the earth's crust; outgushing bodies of this quartz," chilled by contact with cold water, having been broken up into sand, and subsequently spread over the ocean's bottom. (Vol. II, page 780.)

Elsewhere he speaks of a belt of sparry limestone associated with the gneiss of the Welsh Mountain, and traced for a mile and a half, as follows: "Whether this limestone is a true igneous dyke or vein of carbonate of lime, or a closely compressed trough of sedimentary limestone, metamorphosed by heat, I will not undertake to say." (Vol. I, page 90.) These extracts are made not in a spirit of invidious criticism, but because we shall have, farther on, to point out certain errors with regard to these crystalline strata, which had their origin in the exaggerated plutonic views of the author. These, however, he shared with many others of his time.

§ 40. This notice of our author's account of the crystalline rocks of this region would not be complete without reference to the supposed altered Mesozoic sandstone, found associated with several deposits of iron ores, in contact with the gneiss of the Middle district, and at a greater or less distance south of the border of the great belt of Mesozoic rocks. They are, according to him, connected with faults or dislocations; "which are so many ruptured synclinal troughs, enclosing narrow belts or outcrops of a material which, by all lithological analogy, can only be referred to the Middle Secondary sandstone, altered, more or less, by some igneous metamorphic agency," apparently

connected with the supposed folding-up of the sandstone (which has a moderate dip to the north-west throughout this region) in these steep and overturned synclinals.

§ 41. The ore in these deposits, of which many were formerly mined in the valley of Pickering creek, is described as usually lying between gneiss or granite on the one side and a layer of altered red sandstone on the other, both dipping at pretty high angles to the south-eastward; the latter highly crystalline, and holding scales of plumbago, mica and specular iron. The somewhat questionable nature of the "lithological analogy" by which these crystalline rocks are referred to the Mesozoic, becomes evident when we read respecting one of these deposits, that the supposed altered sandstone, from its highly crystalline condition, "greatly puzzles the observer to determine" whether it, like the opposing wall, "is gneiss, or a highly metamorphosed form of the argillaceous red sandstone." Of another adjacent mine, we are told that it is difficult to determine in hand-specimens whether the rock is an altered sandstone or gneiss. There seems no foundation for the notion that these crystalline strata on either side of the ore are anything else than varieties of more or less decayed gneissic rock. The ores of these mines are the usual varieties of brown hematite, sometimes with oxide of manganese, and occasionally with a little pyrites. (Vol. I, page 86-90.)

§ 42. From the foregoing analysis of the descriptions given by Rogers, it is clear that he recognized in south-eastern Pennsylvania crystalline stratified rocks pertaining to not less than seven distinct geological horizons, and presenting marked lithological differences. Two of these divisions belong to the Hypozoic, two to the Primal series, and one each to the Auroral, Matinal and Mesozoic. They are as follows, in ascending order:

1°. *Lower Hypozoic.*—We have seen that the Hypozoic or Gneissic series in the Southern district was supposed to consist of a lower and an upper portion. (§ 26.) The lower division is described as consisting of hard quartzo-feldspathic and hornblendic rocks, chiefly granitoid and syenitic gneisses, with little or no mica.

2°. *Upper Hypozoic.*—The upper portion is described as highly micaceous gneiss, with a great amount of micaceous

schist, and as including also chloritic, talcose and serpentinic rocks.

3°. *Lower Primal.*—The Primal also is divided into two portions, which are lithologically widely dissimilar. Of these the Lower, or so-called Azoic, includes the Primal crystalline schists, and the succeeding Primal lower slates, which closely resemble them; the series consisting chiefly of micaceous, chloritic and talcose schists, often highly silicious, together with hard green rocks, abounding in epidote. This Lower Primal series is declared to be often not distinguishable from the Upper Hypozoic, and like it contains serpentine and it· ssociated rocks.

4°. *Upper Primal.*—The Upper Primal slates, when altered, are supposed to assume a character totally unlike their normal one, and to become in great part a very hard red or reddish-gray jaspery rock, often more or less schistose, including red feldspar, and occasionally seams of epidote. (§ 36). The Primal white sandstone itself, we are told, sometimes becomes altered to a stratified feldspar-rock; but for want of farther details it is not certain whether this is to be confounded with the jaspery feldspathic form of the Primal upper slates.

5°. *Auroral.*—Under this head may be included the altered Auroral limestones, and their included schistose beds (§ 35).

6°. *Matinal.*—The supposed altered rocks of the Matinal series have already been noticed (§ 35).

7°. *Mesozoic.*—The supposed conversion of portions of the Mesozoic strata into a rock difficult to distinguish from the Hypozoic gneiss, has also been referred to (§ 41).

§ 43. My object in thus attempting to condense and systematize some of the scattered details from the reports of Prof. Rogers regarding the crystalline rocks of this region will be made more apparent in the succeeding chapters.

While some of the conclusions appear to me inadmissible, the value of the great mass of minute, conscientious and exact observations which he has accumulated, very many of which I have personally verified, cannot be over-estimated by the student; who must make them the starting-point in any new attempt to advance our geological knowledge of this curious and complicated region.

§ 44. It may here be proper to allude to the geological map of

Canada, and of the eastern United States as far south as the Potomac, published by Sir William E. Logan in the Atlas to the Geology of Canada, in 1864. The Highlands of the Hudson having been referred to the Laurentian system, the South Mountain, recognized by Rogers as a prolongation of these, was correctly represented as belonging to that ancient system ; and in the enlarged edition of the same map, published in 1866, the similar gneiss of the Middle district of Rogers likewise received the name of Laurentian. The whole southern region, including both the Hypozoic and Azoic series of Rogers, was, however, by Logan represented in the map of 1864 as belonging to the so-called Quebec group. This, in the edition of 1866, was modified ; while the whole of the Hypozoic series, as defined by Rogers, was still called the Quebec group, the Azoic series was, with singular inconsequence, referred to the Potsdam. This curious treatment of the scientific labors of another, in thus interpreting the geology of a region which he had never examined, can only be described as an error on the part of the compiler of the geological map in question.

CHAPTER II.

HISTORICAL SKETCH.

§ 45. The history of the ancient rocks of eastern Pennsylsylvania is so closely connected with that of their extension northwards through New York, New England and Canada, that an intelligent understanding of the various questions to which their study gives rise, is only possible to those who are acquainted with the progress of our knowledge of the geology of these regions, from the beginning of the century down to our own time. It will therefore be the object of the present and the succeeding chapter to present an outline of the history of geological research in the regions mentioned.

§ 46. The first distinct attempt to classify the rock-formations of eastern North America was that made by William Maclure, who published a geological map and description of the United States, in 1809, and a second time, in 1817, in a revised edition, which appeared in the Transactions of the American Philosophical Society, (vol. 1, new series,) as a memoir of ninety pages, with a colored geological map and sections. He divided the rocks into five classes: Primitive, Transition, Secondary, Old Red Sandstone and Alluvial. The first of these included

all the crystalline rocks of the great Atlantic belt, and those of northern New York—no allusion being made to those west of the great lakes and the Mississippi. Of the "gneiss formation" of the Primitive, he remarks that it includes, in a great many places, beds from three to three hundred feet thick, of a large-grained granite, running and dipping like the gneiss. "These beds are mixed and occasionally alternate, in the same gneiss, with the primitive limestone, the beds of hornblende and hornblende-slate, serpentine, magnetic iron ore, etc."; —a very good description of the gneissic and granitoid rocks of the Laurentian series.

§ 47. The Transition class of Maclure embraced the great belt of disturbed uncrystalline rocks extending along the west side of the Primitive, from Lake Champlain to Georgia. In it were comprised the anthracite-bearing strata of Rhode Island and of Pennsylvania; while the bituminous coal regions were included, with the horizontal paleozoic rocks of New York, and the whole region west to the Mississippi, and beyond, in the Secondary division. A second and narrow Transition belt, on the south-east slope of the Blue Ridge, was noticed as extending from the Delaware to the Yadkin; including the limestone and other associated schists of the Lancaster and Chester valleys in Pennsylvania. The Mesozoic of the Atlantic belt was designated as Old Red Sandstone; while the newer Secondary and Tertiary of the coasts was included under the Alluvial class.

§ 48. The labors of Amos Eaton mark a new epoch in American geology, and have left a durable impression on the science. In 1824 appeared, under the patronage of Stephen Van Rensellaer, Eaton's "Geological and Agricultural Survey of the Erie Canal," with an engraved section representing the formations from Lake Erie to Boston; to which was added a colored profile of the rocks from Boston as far west as Plainfield, Massachusetts; prepared with notes, by Edward Hitchcock. This work, and the "Geological Text-book" of Eaton, of which the second edition appeared in 1832, are the sources from which we may learn the geological views of this original and ingenious investigator.

§ 49. He announced, as one of the important discoveries of himself and his assistants, the conclusion that each of the great

geological groups in Europe, as well as in America, "commenced with carboniferous slate, and terminated with calcareous rocks, having a middle formation, the centre of which is quartzose." (Text-book, page 23). This is remarkable as the first recognition of the natural law of cycles in sedimentation, now so well understood. The rocks of North America were divided into five great series: I, Primitive; II, Transition; III, Lower Secondary; IV, Upper Secondary; V, Tertiary—each of which was, according to him, a more or less complete triad; having a carboniferous formation (1) at the base, a silicious formation (2) in the middle, and a calcareous formation (3) at the summit. It will be understood that by the term "carboniferous," he means nothing more than a slaty or argillaceous formation, such as is accompanied by carbonaceous matters at various horizons. A careful analysis of his application of this system of classification to the rocks of New York and New England, will be found to throw light upon some questions in geology, which are still obscure and unsettled.

§ 50. The Primitive series of Eaton had for its first or carboniferous division, (I, 1) micaceous, talcose and chloritic slates, with hornblendic rocks, granite or gneiss; the plumbago met with in this division justifying, according to him, the name of a carboniferous formation. The second division (I, 2) was the granular quartz rock of western New England; and the third (I, 3) the granular limerock, including the marbles, of the same region. This Primitive series was supposed to be destitute of organic remains.

§ 51. Besides the gneissic region of New England, Eaton had studied those of the Highlands of the Hudson and of northern New York. To the latter region, now known as the Adirondacks, he gave in 1824, "the general name of Macomb's Mountains;" a large part of the district being then known as Macomb's Purchase (Geol. Sur., page 43). In 1832, he had already examined a collection of the rocks from Lake Huron to Montreal, collected from "the mountain ridge which runs along the north side of the great chain of lakes;" and another series "presenting the entire geology of the whole circuit of Lake Superior." From the study of these he announced that "the Macomb-Mountain range of Primitive rocks extends in a north-

west direction, forming the north-eastern boundary of the great lakes, at least to the distance of one thousand miles from the St. Lawrence at Ogdensburgh." He remarked a great resemblance between the rocks of the Macomb Mountains and the Highlands of the Hudson; adding, "they are remarkably characterized, and distinguished from the Primitive rocks of New England, and most European districts, by their great proportion of hornblende-rocks, and by the presence of tabular-spar, grains of interspersed serpentine, coccolite, colophonite and masses of diallage." (Text-book, pages 68 and 6.) "The gneiss (of the Macomb Mountains) is more nearly in a horizontal position than is usual for rocks of gneiss in New England." (Geol. Survey, page 42.)

§ 52. We come next to his second or Transition series, of which the lower division (II, 1) is an "Argillite" formation, consisting of clay-slate (including roofing-slate) and a gritty variety, designated as wacke-slate. Both of these are described as inclined in their attitude; the wacke having "the same inclination with the argillite, and differing widely from the horizontal or First Graywacke." This latter constitutes the second division of the Transition series (II, 2) and consists of "Graywacke-slate," described as a fine argillaceous sandstone, and of "Millstone grit and gray rubble," more or less conglomerate. The third division (II, 3) comprises the Sparry limestone, found east of the Hudson, the Calciferous sand-rock, identical with that formation in the New York series, and the Transition or Metalliferous lime-rock. Under this latter name, borrowed from Bakewell, were comprised the Birdseye and Trenton limestones; the localities of which, and some of their organic remains, are described by Eaton.

§ 53. To this succeeds the Lower Secondary series, having at its base, as before, a carboniferous division, (III, 1) described as the "Second graywacke slate;" which rests upon the "Transition limerock" (Trenton.) This, which is clearly identified as the Utica and Loraine formations, is overlaid by a second Millstone grit, which is the Oneida, (III, 2) and is described as passing beneath the calcareous division, (III, 3) which includes the Geodiferous limerock (Niagara) and the Corniferous or Cherty limerock (Lower and Upper Helderberg.)

§ 54. The red sandstones and shales of the Medina, the iron-bearing strata of the Clinton, and the saliferous and gypsiferous marls of the Onondaga, with the overlying Water-lime beds, were by Eaton regarded as a "subordinate series embraced in the third regular series." With these red rocks he united certain red beds in the Catskills, as well as the red sandstones of the Mesozoic of New York, New Jersey and the Connecticut valley. The disappearance, to the eastward, of the great mass of red strata which, in central New York, is intercalated at the base of the Helderberg limestones, is noticed by Eaton. The Cherty Secondary limestone is said to be separated at Bethlehem, New York, by only sixty feet of graywacke-slate from the Transition limestone, and to come in contact with it in Catskill in Greene county. These limestones of the Lower Secondary series, it was shown, underlie alike the bituminous coals of western Pennsylvania, and the anthracites, which latter were thus removed from the Transition series, to which they had been referred by Maclure. Eaton showed, moreover, from their fossil plants, that these coals, of both kinds, belonged to the same geological horizon with the coals of Europe.

§ 55. The coal measures were placed in the carboniferous division of Eaton's Upper Secondary series, (IV, 1) which also included the sandstones of the Erie division of the New York series; while the sandstones of the Catskill Mountain were made the second division, (IV, 2) and the third (IV, 3) was supposed to be represented by certain coralline limestones in the Helderberg. It is obvious that Eaton here fell into errors in the succession of strata, which make it no longer profitable to follow him; and we now return to the consideration of his Transition and Lower Secondary series.

§ 56. The Argillite formation of Eaton, which is the lowest division of his Transition series, (II, 1) is said by him to form "the bed and banks of the Hudson," and to appear on the line of section described by him in his "Geological Survey," for a breadth of about twenty miles, from Williamstown Mountain, in Massachusetts to three miles west of Cohoes Falls, on the Mohawk; where it disappears beneath the overlying rocks. The clay-slate of the formation appears to the eastward, in the mountain mentioned, but, along the section, is concealed in great

part beneath the coarser sandy wacke-slate. The two, however, are considered as parts of the same formation, as they both present the same angle of inclination. He is careful, in this connection, to distinguish between the attitude of the stratum, and that of the laminæ of the slate, which are described as forming an angle with the former. (Geol. Sur., 67.)

§ 57. This inclined wacke-slate, belonging to the Argillite formation (II, 1) is carefully distinguished from the graywacke slate, the lower member of the First graywacke formation (II, 2) already noticed; of which it is said "this slate is nearly horizontal, and lies immediately upon the inclined edges of the Argillite, from Canada to Georgia. It is remarkably curved and bent on the Mohawk between the Cohoes and Schenectady, at Saratoga lake, and at the entrance of the Delaware and Hudson canal." He adds, in a note, that "while European geologists have described a change of direction at the meeting of the Lower and Upper Secondary," in which the latter rests horizontally upon the inclined edges of the former, in North America this change takes place at the meeting of the Argillite and the First graywacke." (Text Book, page 74.)

§ 58. The place of this First or Transition graywacke (II, 2) was, according to Eaton, between the Argillite formation (II, 1) and the Transition limestones (II, 3.) Of these latter, the Calciferous sandrock and the succeeding limestones were not shown to rest upon the Argillite; and in fact, as we now know, are found, in the localities familiar to Eaton, directly upon the Primitive gneiss. With them was, however, included the Sparry limestone, known only in the eastern part of the state. He moreover describes numerous large and small masses of sandstone and limestone as occurring included between the laminæ of the Argillite, near the Cohoes Falls, and towards the delta of the Mohawk. These were regarded as small portions of the First graywacke and the Transition limestone; which, he conceived, must have fallen into their places between the laminæ of the Argillite, while this rock was in a soft state. The shelly (*i. e.* fossiliferous) Transition limestone described by Eaton as occurring at Becraft's Mountain near Hudson, is now known to belong to his Lower Secondary limestone (III, 3); it being of Lower Helderberg age.

§ 59. Eaton notices that the acidulous carbonated mineral water obtained by boring at a depth of 480 feet in Albany, is found in the Argillite, and supposes that the similar waters of Saratoga (now said to issue from the Calciferous sand-rock) have a like source. In this connection it is well to recall the acidulous mineral spring found in South Argyle, Washington county, also in the region of the Argillite.

This Argillite was described as containing a flinty slate or Lydian stone, sometimes green and jasper-like, beds of which abound on the Hudson near Albany, and for forty miles below. (Geol. Survey, pp. 69–70.)

§ 60. We have seen that Eaton described a Second graywacke, constituting the lower and middle divisions of the Lower Secondary, and made up, like the First, of an underlying slate (III, 1) and an overlying sandstone and conglomerate; (III, 2) both of which are declared to be scarcely distinguishable from the members of the First graywacke, except by the fact that they overlie the Transition limestones (II, 3). This Second graywacke evidently corresponds to the Utica, Loraine and Oneida formations of the present nomenclature, and thus has its recognized position in the New York series.

§ 61. With regard to the First graywacke, we have seen that the slate which forms its lower member is said to rest in a nearly horizontal attitude on the inclined Argillite formation, in many localities to the west of the Hudson River. On the eastern side of the river the First graywacke, in its completeness, is largely developed. "It is seen resting on the Argillite, near Col. Worthington's on the Little Hoosic, near the east line of Rensselaer county. On ascending the western hill or ridge, the graywacke-slate, rubble and millstone-grit are found in succession. This ridge extends from Canada through the state of Vermont, Washington county, and Rensselaer and Columbia counties, and, crossing the Hudson River, forms the vast mountains of millstone-grit called Shawangunk." Elsewhere we are told that the rubble or conglomerate of the First graywacke "forms the highest ridges between the Massachusetts line and the Hudson," and that the Shawangunk or White Mountain, of Ulster and Orange counties, forty miles in length, "is a continuation of the grit and rubble of the First

graywacke of Rensselaer county." (Geological Text book, pages 74, 93, 123.)

The full significance of these observations of Eaton was not understood till a much later date, as will appear further on.

§ 62. Next to Eaton in the order of time we note the earlier publications of Henry Darwin Rogers. The geological survey of Pennsylvania was begun by him in 1836, and was actively carried on for five years, or until 1841. In his fourth annual report, that of 1840, we find a detailed account of the formations of the south-eastern part of the state. The crystalline rocks included syenite, serpentine, etc., together with gneiss, mica-slate, talc-slate, and "the more or less crystalline limestones," of the Chester and Montgomery valley, lying between the Middle and Southern gneissic districts and, it was said, "obviously, like the former rocks, belonging to a Primary date." While all these rocks were thus included in the Primary system, as it was then generally understood, the limestones of the Lancaster and Kittatinny valleys, and their accompanying sandstones and slates, were said to belong to the Lower Secondary or Appalachian series; while the Mesozoic sandstones were called Middle Secondary. The next annual report, in 1841, contains, with regard to the Primary series, only a few points of detail; and it is not until the final publication of Rogers, in 1858, that we find his later views with regard them, as set forth in the preceding chapter.

§ 63. Simultaneously with the work of Rogers in Pennsylvania, a geological survey of the state of New York, begun in 1837, was in progress. The state was divided into four districts, of which the first, or southern, was confided to Prof. W. W. Mather, and second or northern to Prof. E. Emmons. The central and western districts were entrusted to Messrs. L. Vanuxem and James Hall; but their work has no particular bearing on the questions now before us. Messrs. Mather and Emmons set forth their views on the geology of their respective regions in various annual reports, but we refer for a full exposition of them to their final reports, of which that of Emmons appeared in 1842, and that of Mather in 1843.

§ 64. Resting upon the Primary system of ancient crystalline rocks, in northern New York, there were found, according to

Emmons, the lower members of the New York Transition system. To these lower members Emmons, as is well known, gave the names, in ascending order, of (1) Potsdam sandstone, (2) Calciferous sandrock, (3) Chazy limestone, (4) Trenton limestone, with its associated sub-divisions of the Birdseye and the Isle La Motte or Black River limestone, (5) Utica slate, (6) Loraine shales, (7) Grey sandstone, (8) Medina sandstone. These constituted, according to him, the Champlain division of the New York series. The Grey sandstone, which in Jefferson county overlies the Loraine shales, was by him regarded as the equivalent of the conglomerate of Oneida. This, with the succeeding Medina sandstone, has, by subsequent geologists, been separated from the Champlain and united with the Ontario division; which also includes the Clinton and Niagara formations.

§ 65. To the Champlain division, also, Emmons referred certain red and purple slates which, though not found in the counties to the westward, constitute a narrow belt "which passes through the higher parts of Columbia, Rensselaer and Washington counties, and onward through Vermont into Canada. It is everywhere destitute of fossils." These slates were supposed to belong to the Loraine formation, while to the succeeding sandstone was referred the so-called Graywacke (the Transition graywacke of Eaton,) which forms ranges of hills in the counties just named, "and also occurs at Quebec." It is described as being often coarse and brecciated, having a greenish cement, supposed to be derived from "the chloritic slate along the eastern boundary." To this horizon was also referred a reddish-brown or chocolate-colored sandstone, with interlaminated red shale, stretching along the eastern border of Lake Champlain, and to the west of the Taconic range," in Vermont. Besides this was a mass of limestone immediately succeeding the red sandstone, traversed with numerous veins of calcite and quartz, which is well seen in Bald Mountain, and is the Sparry limestone of Eaton. This rock, according to Emmons, extends through the valley of Lake Champlain, on the east side, and is not to be confounded with the more ancient granular limestone of Berkshire county. All of the rocks mentioned in this section were said to be without fossils, and to be lithologically dissimilar to those of the Champlain division as seen in the val-

ley of the Mohawk and west of the Adirondacks; although they were, at this time, unhesitatingly referred by Emmons to the upper portion of this division of the New York series. (Geology, Second district, pages 121–126).

§ 66. The rocks to which, in his annual reports on the Southern district, Mather had given the name of the Hudson River slates or shales, were by Emmons, in 1842, regarded as a southern prolongation of the above strata from the east side of Lake Champlain. The name of Loraine shales, we are told by him, "is simply a synonym of the Hudson River shales, both terms being occasionally used to designate the same rock. They differ, as has already been pointed out, only in the physical changes which each has sustained. At Loraine they are but slightly removed from a horizontal position, while along the Hudson River they have been fractured and elevated to a high angle, or a steep dip to the east has been given them." (Ibid, page 281.) In Vermont, we are farther told that the Champlain group extends for six miles east of Highgate, while "at Sheldon we leave the Champlain group and pass directly to the Taconic system, consisting at its extreme north, in Vermont, of the same masses of slate and limestone as in the counties of Columbia and Dutchess in New York. Taking a general view of the rocks on the east side of Lake Champlain, and those in the same range, both north and south, we find them consisting of the upper members of the Champlain group. To the east, succeeds the Taconic system, whose width is from six to twelve miles, made up of the same members which compose it in Berkshire county, Massachusetts, with the exception of the granular quartz. This general arrangement extends at least to the latitude of Quebec, presenting one of the longest formations yet known to geologists." (Ibid, page 322.)

§ 67. The Taconic system, as at this time defined, included the granular quartz-rock and granular limestone of the Primitive series of Eaton (I, 2; I, 3,). These were by Emmons separated from the Primitive schists and gneisses, and united with the Transition argillite (II, 1) to form what he regarded as a distinct series; which, though not found between the Primary and the New York series, at the outcrop of the latter in northern New York, was supposed to be intermediate between the

two. It formed the Taconic hills of western New England, occupying, as we have seen, a narrow belt between the Primary on the east, and the disturbed and eastward-dipping rocks, referred to of the Champlain division of the New York series, on the west; the boundary between which and the Taconic system along the Hudson, was not as yet distinctly defined by Emmons. The rocks of these two series, it should be remembered, do not occur within the limits of the Northern district of New York, which had been assigned to him.

§ 68. Mather, in his final report on the geology of the Southern district of New York, which appeared in 1843, or the year following that of Emmons, recognized no distinction between the New York series and the Taconic system, which he regarded as nothing more than the Champlain division of Emmons (excluding therefrom the Oneida and Medina sandstones,) in a modified form. The granular quartz-rock of the Taconic was, according to him, the Potsdam; the granular limestone was the Calciferous sandrock, with the succeeding Chazy and Trenton formations; while the Hudson River Argillite series, including the roofing-slates, represented the Utica slates and the Loraine shales.

§ 69. The district examined by Mather included the Hudson valley from the crystalline Primary rocks of Washington and Saratoga counties on the north to the similar crystalline rocks of the Highlands on the south. He pointed out what he called the Hudson axis, extending from Baker's Falls on the Hudson river, near Sandy Hill in Washington county, southward by Saratoga Lake, Glen's Falls, New Baltimore, Catskill and Kingston. This axis "may be traced farther to the south in the Comfort hills of Orange county, between the Wallkill and the Shawangunk rivers, and is probably an extension of that of Pochunk Mountain, on the New Jersey line." It thus skirts the Hudson river for more than one hundred miles. (Geology, First district, pp. 357, 375, 623.)

§ 70. The course thus defined, which is declared to be "a line of fracture, and an anticlinal axis," is indicated with more preciseness of detail in the Fifth annual report of Mather, (page 66,) where, in its northward extension from Orange county, it

is said that it "crosses the Shawangunk Mountains with a very acute angle, passes near Kingston, thence half a mile east of the fall of Esopus creek, by Saugerties, along the ridge between Catskill village and the Katerskill creek on the road to the Mountain House; near Madison, three miles north-west of Catskill; four miles west of Athens; three miles west of Coxsackie, and about the same distance west of New Baltimore and Coeymans. Its continuation in Albany county is seen where the Normanskill and Mohawk intersect it. It crosses the Mohawk a few miles below the aqueduct, and ranges thence, by Saratoga Lake, to Baker's Falls on the Hudson." To the east of this line the strata present characters very unlike those on the west.

§ 71. This line corresponds to that defined by Eaton between the Transition Argillite and the unconformably overlying Transition Graywacke, a fact which serves to explain the language of Mather, who informs us that "the horizontal and slightly inclined slates and grits of the Hudson River group lying to the west of this axis * * * were formerly considered as more recent strata than the upturned rocks of the Hudson River valley, and as resting unconformably upon them." He, however, maintained and sought to prove the identity of the rocks in the two regions, though he declared that "the upturned rocks are so much modified in their characters by the causes which have deranged their position, that it requires the strongest evidence to convince one that they are no older than the horizontal rocks west of the axis of disturbance." In proof of this view he affirmed that it was possible in many cases "to trace the strata across the axis of disturbance," and, moreover, to find, in various localities among the disturbed rocks, fossils of the Champlain division, especially the graptolites of the Utica slates.

§ 72. The strata of this disturbed region dip constantly to the eastward, and often at angles approaching the vertical. They are also, according to Mather, affected by numerous fractures and faults, which "have deranged all the rocks of the Champlain division and packed them together * * in the utmost confusion." "They are contorted, broken and wrinkled in almost every conceivable manner," and "the repetitions of the same

strata with others lying lower and higher in the geological series, and with frequent apparent inversions in the order of superposition, render it almost impossible to determine, from an examination of the strata on the east bank of the Hudson, what the real order of superposition is. Other difficulties also present themselves, viz: the fossiliferous rocks dip to the east, and apparently plunge under those which have been considered of more ancient formation; and, on the eastern flank of the Hudson valley, these plunge apparently under what we have been accustomed to consider very ancient rocks, as gneiss, granite, mica-slate, etc." That these disturbed strata, destitute of fossils, often with glazed surfaces, more or less talcose in aspect, traversed in parts by numerous quartz veins, and including many "anomalous rocks," were very unlike the Champlain division as seen in the Northern district, to the south and west of the Adirondacks, was thus clearly recognized by Mather, who nevertheless believed the two to be equivalents in geological position.

§ 73. We have next to notice belts of rocks in this region, referred by Mather to the Ontario division of the New York series. First of these, on the west side of the Hudson, is the Shawangunk range, extending from the New Jersey line northeastward a distance of forty-three miles to Rosendale, near Kingston, and regarded as a prolongation of the Kittatinny range of Pennsylvania. The strata of this range are chiefly of sandstone and conglomerate, gray or white, and more rarely red, with slaty layers. They are described as resting unconformably upon the Hudson River slates, and as conformably overlaid by red slates and marls, regarded as representing the Medina; the sandstone itself being supposed to be the equivalent of the Oneida. The dip of this formation is to the north-west, sometimes at a high angle. It is remarkable for its quartz veins carrying sulphuretted ores of lead, copper and zinc; and for its beds of conglomerate, in which the cement is pyrites, enclosing pebbles and grains of quartz.

§ 74. Besides this range, Mather noticed to the south-east another composed of somewhat similar rocks, which are traced at intervals from the New Jersey line, by the west of Long Pond, north-northeast to near Canterbury in Cornwall, Or-

ange county. These were regarded by Mather, and by Rogers. as the extension of the Green-Pond Mountain range of New Jersey; and were supposed by the latter to be of the age of the Mesozoic sandstones which are found to the south-east of them. Mather, however, considered them as the geological equivalents of the Shawangunk range, which they resemble lithologically; and described the occurrence of shales with organic remains of Lower Helderberg age, associated with the conglomerate of this series, at Townsend's iron mine in Cornwall. These sandstones, conglomerates and shales are well displayed in Pine Hill and Blooming Grove, and in Belvale and Skunnemunk Mountains, in Orange county.

§ 75. The important fact connected with this series of rocks is that, according to Mather, similar rocks, consisting of coarse white, gray and greenish sandstones, red and white conglomerates and red shales, "are found on the east side of the Hudson valley, ranging from Fishkill, near Matteawan, through Dutchess, Columbia, Rensselaer and Washington counties into Vermont, in West Poulteney; a distance of more than 200 miles from their southern termination in New Jersey." These rocks frequently occupy two or three parallel belts one or two miles apart, and are often associated with limestone in Orange county, as well as in the counties east of the Hudson River; where they rest on the Argillites of the Hudson River group, and dip to high angles to the eastward; while in the Highlands they are in contact with the Primitive gneiss, and have a similar inclination, or are even vertical in attitude. In many instances noticed by Horton (the assistant of Mather) in Warwick and Munroe, Orange county, where this sandstone formation (Graywacke) occurs on the northwest side of the gneissic hills, "the lines of bearing and dip of the Graywacke coincide with those of the Primitive, and the Graywacke has the appearance of passing beneath the Primitive rock. At the western base of Goosepond Mountain, and of Sugar Loaf Mate, the slate has the same position in reference to the Primitive, and exhibits precisely the same appearance."

§ 76. The conclusions of Horton from the study of these rocks, chiefly in Orange county, may be thus summed up:

1°. The slate (Argillite) and the Graywacke of the Hudson

River are interstratified with each other, forming a contemporaneous series (A); and the limestone of Neeleytown and the blue limestones of Newburg, Munroe, Blooming Grove and Goshen are interstratified with this series.

2°. The grit of Shawangunk Mountain (B) rests unconformably upon the basset edges of the Argillite and Graywacke series.

2°. The grit and Graywacke of Pine Hill, Blooming Grove, Belvale and Skunnemunk Mountains (C) also rest on the same Argillite and Graywacke series (A); whether unconformably is not stated.

4°. The "conglomerate and fossiliferous limestone of Goshen" (D) are newer than the blue limestones mentioned above. since, like the rocks C, they rest upon the series A.

5°. The limestone at the foot of Shawangunk Mountain rests conformably on the Shawangunk grit, and is overlaid by the Graywacke of Deer Park, (the sandstones of the Devonian series. (Geology, First district, page 580).

These interrupted belts of sandstones, conglomerates and red shales, (the grit and graywacke,) are traced, according to Mather, from New Jersey to Vermont; and although their identity with the Shawangunk range was not certain, they were by him referred, like it, to the Ontario division of the New York series. (Ibid, pages 362–365).

§ 77. Emmons, as we have seen, did not, in 1842, clearly define the limits between the Taconic system and the rocks, regarded as belonging to the Champlain division, which bounded it on the west; the position of the two giving rise, according to him, to "many doubts and perplexities as regards the true limits of either system." Far from including in the Taconic system the whole of the highly disturbed region along the Hudson valley, this system was, at that time, confined to a narrow belt along the western border of the Primary, while the strata between this belt and the river were still included by Emmons in the Champlain division.

§ 77A. According to Mather, the rocks of the Taconic system. as thus limited, have the same dip and strike as the rocks of the Champlain division, "and apparently overlie them;" the dip of the strata being easterly, and at angles of from 30° to

90°. "Although the rocks all dip in the same general direction, similar strata, at no great distances, are frequently reversed in the relative order of their supposition." It was impossible to draw any line of demarkation between the rocks of the Taconic system and those of the so-called Champlain division, in this region, and Mather was forced to the conclusion that they belong to one and the same series. In his own words, he conceived that "the Taconic rocks are the same in age with those of the Champlain, but modified by metamorphic agency and by the intrusion of plutonic rocks." (Geology First district, page 438).

§ 78. Similar conclusions were reached by H. D. and W. B. Rogers, as the result of sections made across portions of the region in question, and set forth in a communication to the American Philosophical Society in 1841; in which they asserted that the Taconic rocks were identical with those of the Hudson valley, and referred both to the Champlain division of the New York series. They declare that where "the exact order of superposition of these rocks and the Primary can be examined, it is found; first, that the granular quartz either rests upon or pitches immediately under the gneiss or granitic rocks; second, that the limestones lie next in order from the gneiss or granite, either in super or sub-position; and, third, that the slates next follow." (Ibid, page 423).

§ 79. Before proceeding further in the description of the Taconic rocks, we may notice the views of Mather and Emmons, and of some others who had preceded them, regarding the crystalline formations, which are found north, east and south of these, in the state of New York. These crystalline rocks were described by Mather under two heads, the Primary and the Metamorphic divisions. To the former were referred the granitoid, gneissic and hornblendic rocks of the Highland chain, found in Putnam, Westchester, Dutchess, Rockland and Orange counties; with which were also classed the similar rocks of Saratoga and Washington counties, included within the northern part of the First district. The rocks of this range, as is well known, are continued, with the same lithological characters, in the South Mountain range into Pennsylvania; where they constitute the Northern and Middle gneissic dis

tricts of Rogers (§ 12). No attempt was made on the geological map of New York to trace the limit between these Primary rocks and the succeeding Metamorphic series.

§ 80. The rocks to which he gave the name of Metamorphic were divided by Mather into two groups. Of these the first and most important is that series described by Emmons as the Primary belt, bounding on the east the Taconic range in Vermont and western Massachusetts. It enters the state of New York, according to Mather, in the northeast corner of Dutchess county, extending thence along the southeastern side of the Highland range to the Hudson, and to Long Island, and including the county and city of New York. The rocks of this belt are described, to the north of the Highlands, as chiefly micaceous, talcose and chloritic slates, with quartzites and more or less crystalline limestones or dolomites; while south and east of the Highlands, in Westchester and New York counties, are found still more crystalline limestones, associated with mica-schists, micaceous gneiss, hornblendic rocks, granite, syenite and serpentine; the latter three being regarded as plutonic rocks. In this Metamorphic series are included, as will be seen, the limestones, mica-schists and gneisses of Manhattan island, as well as the belt of steatite and anthophyllite-rock, with serpentine, found on the western side of the city of New York; which is apparently related to the similar rocks of Hoboken and Staten Island. At Stony Point, on the Hudson, the hornblendic rocks are said to be traversed by parallel dykes of serpentine and of greenstone, the latter being penetrated by magnesian minerals like those of Hoboken. Another similar belt, with serpentine, is found near New Rochelle.

§ 81. The Taconic rocks pass to the west of the Hudson, immediately north of the Highland range, which, for a considerable distance to the north-east, divides them from the Metamorphic belt, but where this separating range disappears, and the Taconic and Metamorphic rocks come in contact, "no well marked line of distinction can be drawn, as they blend into each other by insensible shades of difference." The difficulty of determining the relations of these rocks is rendered greater by the fact that the whole series dips to the eastward, generally at a high angle, so that the newer seem to pass below the older, and

these, in their turn, plunge, apparently, beneath the granitic and gneissic and micaceous rocks which lie to the eastward of them. (See the words already quoted, § 72.) The final conclusion of Mather was that the rocks of this Metamorphic belt, (in which he included, moreover, all of the crystalline rocks of western New England) were nothing more than the Potsdam sandstone, the Calciferous sandstone and the Trenton (Mohawk) limestones, together with the slate rocks of the Hudson valley, in an altered condition; "that they were, in fact, the rocks of the Champlain division, but much more altered and modified by metamorphic agency than the Taconic rocks," which he calls "imperfect Metamorphic rocks." Elsewhere he concludes that "the limestones, at least, and probably the associated micaceous gneiss, mica-slate, hornblende-slate and hornblende rocks, are Metamorphic rocks, more recent in their change than the Taconic rocks. In fact they are nothing more than the rocks of the Champlain division, modified greatly by metamorphic agency, and by the intrusion of granitic and trappean aggregates." (Report of First district, pages 464, 626, 628.)

§ 82. Further on, he expresses the opinion that many of the rocks called by him Primary, including even certain of the gneisses, may perhaps be of the same age as the Metamorphic rocks. This view was extended to what, by himself and others, had been called the Primary limestone of the Highlands, and which, in his report of the First district, makes a second group of Metamorphic rocks. The crystalline limestones of this group are, according to Mather, mineralogically very distinct from those of the preceding division, and are characterized by containing graphite, serpentine, chondrodite, hornblende, pyroxene, magnesian mica, scapolite, apatite, spinel, sphene, and many other crystalline mineral species. As described by Horton, the assistant of Mather, the limestone is said to be "interstratified with the granitic and hornblendic rocks," and again, "in contact with the granite, the gneiss and hornblende rocks; sometimes between them, sometimes above them, and sometimes beneath them. It is not stratified." (Ibid, page 677.) The conclusion adopted by Mather, from a survey of these rocks in the Highlands, in Orange county, New York, and Sussex county,

New Jersey, is that the crystalline limestones, which are largely displayed in this region, together with their associated granitic and hornblendic aggregates, are nothing more than modifications of the Potsdam sandstone and the accompanying fossiliferous limestones of the Champlain division. In the Warwick valley, he tells us, "the limestones can be easily traced through all the changes from a fossiliferous to a crystalline white limestone, containing crystallized minerals and plumbago;" and he extends the same view to the similar limestones with the gneissic rocks of Saratoga and Washington counties. (Ibid, pages 465, 476, 486.) From the interstratification of these crystalline limestones with gneissic and hornblendic rocks, he was thus forced to admit the paleozoic age of these latter, and hence the doubt which, as we have seen, was thrown by him upon the age of certain of the gneissic rocks previously designated as Primary.

§ 83. To the student of geology, who is aware of its now universally admitted fallacy, it is no small interest to trace the history of this view of metamorphism, as applied to the rocks in question. Nuttall, who is believed by Mather to have first enunciated it, says, in 1822, (American Journal of Science, [I] vol. V, page 267,) in describing these limestones in Franklin, Sussex county, New Jersey: "The crystalline calcareous rock, which here alternates with granitines of feldspar and quartz, or with beds of syenitic granite, disappears, and a confluent graywacke, almost porphyritic, and contemporaneous, apparently, with the other formations, appears directly overlaid by a bed of leaden, minutely granular secondary limestone, containing organic remains of the usual shells and corallines, and layers of blackish hornstone." These rocks were farther described as passing into each other, the graywacke imperceptibly blending with the granitic and syenitic rocks of the Highlands.

§ 84. These views were adopted by H. D. Rogers, so far as regards the crystalline limestones of the Highlands of New Jersey, and are set forth with great fullness by him in his final report on the geology of that state, in 1840, which is quoted by Mather. He however made an important addition to the hypothesis, for while Mather was content, in a general way, to

imagine that heat had effected the supposed changes in the paleozoic sediments, Rogers endeavored to show that eruptive or plutonic rocks had been the source of the heat which had altered the fossiliferous limestones. We have already noted the extreme length to which he carried his plutonic views, (§ 39,) and it will be found that he is not at a loss for igneous rocks. The well-known interstratified deposit of franklinite, with oxide and silicate of zinc, in Franklin and Sterling, New Jersey, is, according to Rogers, an "intrusive vein," injected betwen the gneiss and the overlying Transition limestone, which, by the action of "the intensely heated metalliferous vein," has been changed into a sparry calcareous rock, filled with crystallized minerals. In another locality in the Highlands he has described "a granitic dyke or vein" consisting of quartz, carbonate of lime, feldspar, augite and mica, with spinel and sapphire. This is called a "vein of igneous matter," which, having been itself in a melted condition, is supposed to have fused the limestone with which it came in contact; the two rocks becoming so mingled that no line of demarkation between is now visible. According to him, there him, there can be seen, in certain localities, a gradation from the crystalline graphitic limestone to the blue and earthy limestones, which he subsequently named the Auroral. Notwithstanding that the dip of these limestones was here generally to the north-west, at moderate angles, while the crystalline sparry limestone, like the accompanying gneiss, had a steep dip in the opposite direction, Rogers was able to find a section in which these latter rocks had a dip apparently conformable with the blue limestone and the Primal sandstone, thus supporting his view that the whole belonged to one series. It may here be remarked that some portions of the ancient limestones of the gneissic series are fine-grained and bluish in color, so that they resemble not a little the more crystalline beds of the Auro[illegible] This was the only fact underlying the assumption of [illegible] morphic origin and the paleozoic age of the crysta[illegible]lim[illegible] stones of the Highlands, a notion which the labors of Prof. Cook and his associates of the present geological survey of New Jersey have shown to be a fallacy, as those of Emmons in northern New York, and of the geological survey of Canada, have long since demonstrated for the latter regions.

§ 85. While he adopted to a very great extent the views of Nuttall and of Rogers, Mather did not apply them to all the crystalline limestones. He refers to the view of Emmons that crystalline limestone is an eruptive rock, and says that there are many examples in the Primary regions of Washington county which serve to demonstrate this, and leave little or no doubt that the rock was "injected in a fluid state." In another locality, a cliff of white crystalline limestone is said to include "a mass of stratified hornblendic gneiss distinctly imbedded in it." (Geology, First district, page 485.)

§ 86. Emmons, in his final report on the Northern district of New York, in 1842, described as Primary the crystalline rocks of the Macomb Mountains; to which region the name of the Adirondacks, at first applied to their highest group of hills, has since been extended. It embraces the crystalline rocks of Washington and Saratoga counties, which were included in the Southern district and noticed by Mather. The crystalline rocks of this great Primary region were, by Emmons, divided into two principal groups: 1st, Unstratified; including granite, hypersthene rock, crystalline limestone, serpentine and rensselaerite; 2d, Stratified; embracing gneiss, hornblende-rock, syenite and steatite. In a subordinate group were included certain porphyry and traps traversing the rocks of the New York series, (which, in parts of the region, overlie the Primary) and the magnetic and specular oxides of iron, found in the gneissic and hypersthenic masses, and, like the 1st group, regarded as unstratified. Granite, according to him, was rare, and was so often found passing into gneiss that he regarded the distinction between the two rocks as an unimportant one, and declared that it was in many cases impossible to determine whether a given rock belonged to the one or the other of these.

§ 87. It should here be noted that Emmons did not accept the so-called metamorphic theory of crystalline rocks, adopted by Nuttall, Rogers and Mather, which maintains gneiss to be the result of an alteration of uncrystalline sedimentary matters, of which process granite is only the last term. The view held by Emmons still finds favor with a considerable school of geologists, according to whom the stratified crystalline rocks are of igneous origin, and owe their banded structure to an arrange-

ment of their mineral constituents by movements while yet in a liquid state, so that gneiss may be defined as a laminated granite. These stratified rocks, which Emmons designated by the term Pyrocrystalline, were regarded as igneous, and in no sense of sedimentary origin. The associations of the crystalline limestones with the granitic and gneissic rocks were such that these too were regarded as of igneous origin; a view which he maintained at length, in opposition to the theory of their sedimentary nature supported by Hitchcock, Rogers and Mather. The same view was by him extended to the serpentine and rensselaerite, so often associated with these limestones. The igneous nature of crystalline or primary limestone was at that time taught by many European geologists of distinction, and a similar view of the nature of serpentine is still prevalent.

§ 88. The name of hypersthene-rock, (previously applied to a similar aggregate in the Western Islands of Scotland, by Maculloch,) was given by Emmons to a formation which occupies the greater part of Essex county, New York, forming the highest hills in the district. It was correctly described by him as consisting chiefly of labradorite, frequently intermixed with hypersthene; while certain varieties of the rock contained also hornblende, epidote, mica and garnet. An unstratified rock like granite, it was, like it, declared to be intermixed with and penetrated by crystalline primary limestone, marked, as elsewhere in the Adirondack region, and in the Primary rocks of the Highlands, in the Southern district, by pyroxene, hornblende, scapolite and apatite. (Geology, Second district, pages 39,40).

§ 89. We have already set forth the views of Emmons regarding the Taconic and New York systems, as taught by him in 1842. In 1846, appeared his volume on the "Agriculture of New York," in which, while giving a summary of the geology of the whole state, he revised his opinions on the Taconic and the Champlain rocks. The former were, in 1842, restricted to a narrow belt between the Primary rocks on the east and the New York series on the west; this position giving rise, in the language of Emmons, "to many doubts and perplexities as regards the true limits of either system." The disturbed strata on the east side of the Hudson, thus referred by Emmons to the Utica and Loraine formations, could not, according to

Mather, be separated from the Taconic, which he therefore regarded as one with the Champlain division. In 1846, Emmons himself recognized this identity, but extended to the whole the name of Taconic. He explained that he had, in 1842, referred the Taconic roofing-slates to the upper part of the Champlain division on account of some markings on them, which were mistaken for the graptolites of the Utica formation.

§ 90. There remained, however, this important difference between Mather and H. D. Rogers, on the one hand, and Emmons on the other, that while the former geologists maintained that the whole of the disturbed strata in question belong to the Champlain division, the latter asserted that they constitute an older series, upon which the different members of this division rest unconformably. He had previously declared the Taconic system to be "equivalent to the Lower Cambrian of Prof. Sedgwick," (Geology, Second District, page 163,) and he now asserted that "the Taconic system occupies a position inferior to the Champlain division of the New York system, or the lower division of the Silurian system of Mr. Murchison." (Agriculture of New York, page 55.)

§ 91. In this last quoted volume, giving the results of his more extended studies, it is said that "the Taconic slate, with its subordinate beds, occupies almost the whole of Columbia, Rensselaer and Washington counties in New York," and extends eastward to the base of the Taconic hills, on the frontier of New England. Crossing the Hudson from Dutchess county, it was subsequently traced through Orange county, and across northern New Jersey into Pennsylvania, and thence, along the western base of the Blue Ridge, into Virginia. (Emmons, American Geology, page 117.)

§ 92. The meeting of the Taconic slates and the Hudson River (Loraine) slates was said to be visible at various localities in the valley of the Hudson, along the western side of which the Loraine slates are found overlying unconformably the Taconic slates, which finally pass below the Loraine in the valley of the Mohawk. Other members of the Champlain division were also declared to rest unconformably upon the Taconic slates, to the east of the Hudson. In his volume of 1846, Emmons describes a section from Greenbush, on the Hudson, eastward to

Chatham Four-Corners, the rocks, a series of eastward-dipping slates, limestones and quartzites, being represented throughout as Taconic, with the exception of small outliers of Loraine shales and Calciferous sandrock, near the Hudson. In another section across the Hudson, at Poughkeepsie, the strata on both sides are called Taconic, and are represented as succeeded, one mile west of the Hudson, by Hudson River (Loraine) shales. (loc. cit., plate XVIII.) The continuation of this section eastward from Poughkeepsie is also designated by him as Taconic. By comparing these data with the geological map of New York, and with the statements of Mather, given above, it is clear that the Taconic slate formation in eastern New York was co-extensive with the disturbed, altered and anomalous Hudson River group of Mather, and that the included and underlying limestones of the region were, in like manner, the limestones of the Taconic system of Emmons.

§ 93. We have next to consider those overlying rocks which Mather, in this region, referred to the Oneida and Medina formations of the Ontario division. In 1842, Emmons placed at the summit of the Loraine what he called the Gray band, which he considered as the equivalent of the Oneida, and included this, with the Medina, in the Champlain division; but in 1846 he transferred the Medina to the Ontario, making the Champlain division to terminate with the Gray band or Oneida. Thus, when Mather speaks of the rocks in question as belonging to the lower part of the Ontario division, and Emmons assigns them to the upper part of the Champlain, it will be understood that both refer them to the same horizon; the latter geologist including in the Oneida certain red shales regarded by Mather as pertaining to the Medina formation.

§ 94. Mather, as we have seen, traced these overlying rocks, with the help of Rogers and Horton, from New Jersey, through Orange county, New York, to the west bank of the Hudson river, and thence, crossing into Dutchess county, along the eastern side of the Hudson, through Columbia, Rensselaer and Washington counties, to West Poultney in Rutland county, Vermont, near the head of Lake Champlain. Emmons, in 1842, referred to the Oneida the sandstones occurring farther north, along the east side of this lake, in the towns of Addison, Char-

lotte, Burlington and Colchester; while the limestones of St. Albans, Swanton and Highgate were supposed by him to belong to the summit of the Loraine. He further pointed out that these rocks, (regarded collectively as belonging to *the summit of the Champlain division*), extended southward from Vermont, through the eastern counties of New York already named, where they had been studied and described by Mather, and northeastward through Canada, as far as Quebec.

§ 95. Between 1842 and 1846 the views of Emmons with regard to these rocks had undergone a complete change, and he now transferred them to *the lower part of the Champlain division*, and regarded them as a modified form of the Calciferous sand-rock of the Mohawk valley, which, to the eastward, he declared to include various forms of rock, and to be "protean" in its characters. To one of these varieties he referred the red sandstones of Addison, Charlotte and Burlington, with their interstratified red and chocolate-colored slates, and declared that these sandstones, through an admixture of carbonate of lime, pass into a gray calcareous sandstone, forming the upper part of the series; while beneath the red sandstones were beds of a blue compact limestone, sometimes fossiliferous. This limestone, he declared to be the lowest member of the series, and to rest directly upon the Taconic black slate.

§ 96. This whole formation was supposed by Emmons to occupy the position of the so-called Calciferous sandrock of northern New York, which is beneath the Chazy limestone and above the Potsdam sandstone. This latter formation, according to him, was wanting in eastern Vermont and eastern New York, as well as in the valley of the Mohawk, where the Calciferous rests directly on the Primary. An irregular belt of this modified and protean Calciferous sand-rock, according to Emmons, is traced from the Canada line, through eastern Vermont, into New York. "In the counties of Dutchess and Orange it forms an imperfect belt. In Columbia, Rensselaer and Washington counties its continuity is still more broken. It occupies in the last three counties the knobs, as at Greenbush, Greenwich and Whitehall. These knobs lie contiguous to the Hudson; it is, however, still found sparingly twenty miles east of the Hudson river, as at Hoosic, and, as I now be-

lieve, near Pownal, Vermont. * * * Probably this broken range or belt runs obliquely across Columbia and Dutchess counties, and thence onward into Orange, crossing the Hudson river a few miles above Newburg. We can hardly avoid the inference that this belt was once continuous, and formed an important mass, overlying the Taconic slate." * * * In the Hudson valley insulated patches of these rocks, sometimes limited to a few acres, and sometimes miles in extent, are met with, often forming the highest points in the region. In favorable localities they occupy a position not to be mistaken, and rest upon the slates of the Taconic system. The limestone, which appears at the base of this series, reposes upon the upturned edges of the Taconic slates, as is seen in many quarries. As the result of the great fractures and disturbances in this region, the rocks of the Calciferous series are also sometimes found "in the valleys, outcropping from beneath the Hudson River (Loraine) slates which have been preserved from denudation." (Agriculture of New York, pages 118–122.)

§ 97. With regard to the overlying rocks, which form the upper members of the Champlain division, the Utica slate has, according to him, "but a slight claim to the distinction of an independent" formation, constituting, as it does, the transition from the Trenton limestone to the Loraine shales; and in organic remains, and in other characters, partaking more of the characters of the latter. In Jefferson and Lewis counties he remarks that there is an alternation of strata having the aspect of the Utica, with the Loraine shales, which latter, in their upper part, alternate with the thick-bedded sandstones of the Gray band, already mentioned, so that it is not easy to define the limits of the two. These heavy beds of the Loraine are seen in the valley of the Rondout in many places east of the High Falls, on the Hudson and Delaware canal, and to great advantage at their northern outcropping along the termination of the Helderberg range, where appear alternating beds of sandstone and black slate, the latter from twelve to eighteen inches in thickness. About 700 feet of these strata are there exposed, with a slight dip to the south-west. "It is here almost destitute of fossils, and in this respect resembles the beds which occur in patches upon the east side of the Hudson, along

the Western (Boston and Albany) railway. These latter beds may be clearly distinguished from the slates and shales of the Taconic system; they neither conform with them in dip nor in strike, and, except in the immediate vicinity of the great northern fracture of the Hudson valley, their dip and disturbance are not excessive." These rocks are said to form a small range between Chatham Centre and Chatham Four-Corners, where they lie in deep troughs, and are exposed in the railway cuttings." (Agriculture of New York, pages 123–125, 128.)

§ 98. According to these statements of Emmons, we have then in the region of sedimentary rocks, along the valley of the Hudson, three distinct series of strata: I. the slates and limestones of the Taconic series; II. The sandstones, slates and limestones belonging to the Calciferous sand-rock of the Champlain division, resting, in apparent unconformity, upon the former, and partially removed by erosion before the deposition of III, a series of shales and sandstones belonging to the superior portions of the Champlain division, which have, in their turn, been to a great extent eroded, but are found in patches overlying, unconformably, alike the strata of I and of II.

§ 99. This condition of things implies that there occurred a change of level immediately preceding the time of the Utica and Loraine formations, (III,) which allowed these to be deposited not only on the Trenton limestone, but also on the older series, (I and II.) That such was really the case is evident from other facts. The Laurentian region of the Adirondacks and Laurentides was not, at this time, as has been so often said, the nucleus of a growing continent, but one of the higher parts of a subsiding one, and the deposition of the rocks of the Champlain division was marked by more than one period of disturbance. Upon its ancient gneiss we find reposing directly, in in different localities, the Potsdam, the Calciferous, the Trenton and the Utica formations. The deposition of the Trenton marks a time of subsidence, during which, along the Laurentides, the deep sea extended far and wide to the north, and the marine limestones of the Trenton, overlapping the lower members of the Champlain division, were deposited over the regions to the north of Lake Ontario and of the lower St. Lawrence, (and as far northeastward as the basin of Lake St.

John, on the Saguenay,) directly upon the submerged Primary or Eozoic rocks.

§ 100. After this period, and before the succeeding time of the deposition of mechanical sediments, extensive movements took place in the regions of the Ottawa valley and Lake Champlain, which allowed these sediments to be laid down alike on the Primary rocks and on the older members of the Champlain division. Evidence of this can be seen on the geological map of Canada, where, on the northern border of the Ottawa basin, and immediately south and east of the city of that name, is shown, in the counties of Carleton and Russell, an isolated patch of Utica slates, overlaid with gray calcareous sandstones, holding the fossil remains of the Loraine and associated with red shales. This outlier, which has its greatest length, about twenty miles, from east to west, reposes transgressively alike upon the Calciferous, Chazy and Trenton formations, all three of which, with a slight eastward dip, towards the centre of the basin, appear successively, in passing from west to east along the southern border of this unconformably overlying area of the newer strata of the Champlain division, which are here let down along the north side of an east and west dislocation. (Geology of Canada, pages 118, 127, 165, 219.)

§ 101. Emmons has described an analogous occurrence in the valley of Lake Champlain, where, in Essex county, near Split Rock, on the south side of Whallon's bay, the Utica slates overlap the older members of the Champlain series, and "rest visibly upon the Primary" or ancient crystalline rocks of the region. (Geology, Second district, page 278, and plate VIII, section 4.)

§ 102. In 1855, appeared parts I and II of the "American Geology" by Prof. Emmons. The second of these is devoted to an exposition of the Taconic system and of the Champlain division of the New York series, and may be supposed to contain the author's final conclusions with regard to the important questions raised in his publications of 1842 and 1846. In 1842 he included in the Taconic system the granular limestones of Stockbridge, the granular quartz rock, the so-called magnesian slates, and the sparry limerock, besides a group of strata, not very clearly defined, designated by him as the Taconic

slates; the order of succession among all these being, according to Emmons, unsettled, or "at least not clearly established." The line of demarkation between the Taconic slates (the Transition Argillite formation of Eaton) and the New York series was also undetermined, and the roofing-slates of Hoosic, and some other localities in that region, were then referred to the latter, in deference to the opinions of his colleagues, though, as he tells us in 1846, contrary to his own judgment. Certain organic forms, resembling the graptolites of the Utica formation, found in these slates, were, in 1842, regarded as evidence that they belonged to the New York series, but subsequently Emmons came to regard them as marine plants, of which he describes some with narrow and others with "wide fronds." One of these supposed plants from Hoosic was figured by him in 1846, under the name of *Fucoides simplex*. (Agriculture, New York, page 71, and pl. XVII, fig. 1.) This, according to Hall, had been previously named by Eaton, *Fucoides secalinus*, and was by Hall, in 1865, called *Graptolithus* (*Diplograptus*) *secalinus*, and referred by him to the so-called Quebec group. It is, however, undescribed. (James Hall, Geol. Survey of Canada, decade II, pp. 57, 64.) Emmons had already, in 1855, recognized the graptolitic character of the organic remains from the Hoosic slate. (American Geology, II, page 40.)

§103. In 1846, the succession of the Taconic rocks was defined by Emmons as follows, in ascending order: (1) Granular quartz rock; (2) Magnesian slate; (3) Stockbridge limestone, which was declared to be interstratified with the Magnesian slate, so that the two were to be regarded as forming but one rock. To these succeeded (4) the Taconic slate, under which head was included, besides a soft Magnesian slate, resembling that below the Stockbridge limestone, a great variety of other rocks. Among these were coarse greenish chloritic sandstones, gray sandstones; limestones, gray and silicious, blue and compact, and sparry and brecciated; besides coarse and fine slates, green, black, red and chocolate-colored, together with fine-grained roofing-slates. (Agriculture, New York, page 66.) Above this heterogeneous group, included under the common name of Taconic slates, was placed a black slate, sometimes including calcareous beds, which was regarded as the summit of the Taconic

system. It was in this slate, on Bald Mountain, in Washington county, New York, that were found the trilobites described by Emmons as *Atops trilineatus* and *Elliptocephala asaphoides*. (Ibid, page 64.) He afterwards supposed that there are in the region described, on the frontiers of New York and Massachusetts, roofing-slates at two horizons in the Taconic system; the one, a fine blue slate, occupying a position below the sparry limestone, and the other above this limestone, including the slates of Hoosic, which yield the graptolitic forms already noticed. (Amer. Geology, II, pages 39–41.)

§ 104. In 1855, Emmons proposed to divide the Taconic system into two parts, which he called respectively Lower and Upper Taconic, and between which "the line of demarkation is tolerably well defined." The Lower Taconic includes the Granular quartz rock, at the base, the Stockbridge limestone, with its associated Magnesian slates, (to which the name of talcose slates was then given,) and terminates with the similar slate overlying the limestone. (Ibid, II, page 12.) Further on, he describes with some detail, the Lower Taconic series as seen in Williamstown and Adams, in Berkshire county, Massachuchusetts. The lowest division of this series has, at its base, a conglomerate of rounded and angular pebbles of quartz in a talcose paste. This, in some points, rests upon a granitic rock, of which it then includes the fragments. Succeeding this there are several repetitions of quartzose sandstones and conglomerates, with soft talcose slates, having an aggregate thickness of about 1,200 feet, which are well seen in Oak Hill, described as a synclinal mountain rising 1,700 feet above the valley of the Hoosic. Above this comes the Stockbridge limestone, 500 feet in thickness, and more or less interlaminated with the talcose slates. 2,000 feet of similar slates, overlie the limestone, and are seen in Saddle and Graylock Mountains; thus making the entire thickness of the Lower Taconic series in this region about 3,700 feet. (Ibid, II, pages 15–18.)

§ 105. The same succession and similar characters are by Emmons ascribed to the Lower Taconic rocks in their southward extension through Pennsylvania, Virginia, North Carolina Tennessee and Georgia. He has given the details of a section which is well displayed at the Warm Springs, in Buncombe

county, North Carolina, on the French Broad river. The Lower Taconic strata rest unconformably upon the ancient gneisses, (which here dip to the south-east,) and are inclined to the west, the measured thickness being about 3,000 feet. (Amer. Geology, II, page 24.)

§ 106. In his "Manual of Geology," published in 1860, the Lower Taconic is described, in general terms, as consisting of a conglomerate at the base, succeeded by three masses of quartzite or sandstone, separated by talcose slates; the upper quartzite being often vitreous, while the lower is a sandstone. To this succeed, as before, the granular limestones, with their associated and overlying slates, (including some roofing-slates,) the total thickness being about 5,000 feet.

§ 107. The Upper Taconic series is very distinct in its characters from the Lower Taconic, and comprises the various rocks which have been described as belonging to the Taconic slates. It has, at its base, coarse slates and sandstones, which are greenish in color, the masses often resembling a greenstone, and being "rather chloritic than talcose." Chlorite, and "perhaps the debris of hornblende" are said to be present in these rocks, and a chloritic matter is described as forming in many cases the paste of the sandstones and conglomerates, which belong to the base of this series and often rest upon the crystalline rocks. The higher part of the Upper Taconic is said to be very variable or "protean" in character; including brown-weathering calcareous sandstones and olive-colored sandstones, beds of quartzite, with green, purple and red-roofing slates, blue limestones and sparry limestones; while towards the summit are conglomerates with black shaly limestones, the series terminating with a fine black slate. This description may be compared with that previously given of the Taconic slate group. (§ 103.) The upper part of this Upper Taconic series is fossiliferous, containing remains of graptolites, fucoids and crustaceans. (American Geology, II, pages, 12, 13, 50.)

§ 108. The Upper Taconic series is displayed in a section from near Comstock's Landing, in Washington county, New York, eastward for ten miles to Middle Granville. The series, (having an average dip of 40° to the eastward,) begins, to the westward, with thin black slates, and ends, to the eastward, with

thick-bedded greenish chloritic sandstones and conglomerates. There is in this series no representative of the granular quartzites, the limestones, or the talcose slates of the Lower Taconic, and "the roofing-slates of Columbia and Rensselaer counties are absent." To the westward of this section, at Comstock's Landing, the Potsdam sandstone is seen to rest upon the gneiss, and passes eastward below the overlying Calciferous sandrock and Chazy limestone. Further eastward, the Calciferous, with its characteristic fossils, is seen to rest unconformably upon the beds of the Taconic slate. The Upper Taconic series, it will be understood, here makes its appearance from beneath the lower members of the New York series, by which the contact of the Primary gneiss with the Upper Taconic rocks is concealed. (American Geology, II, page 52.)

§ 109. The Upper Taconic rocks in this section dip to the eastward at an angle of about 40°, so that the black slates, at its western end, seem to pass beneath all the other members, and the green sandstones, at the eastern end of the section, appear to overlie all the others. This is directly contrary to the succession already given, where the green sandstones are declared to be at the base, and the black fossiliferous slates at the summit of the series. This apparent inversion is, as we have already seen, the general condition of the stratified rocks along the eastern base of the Atlantic belt farther southward, in New York and along the Blue Ridge, as described by Rogers and by Mather. The latter, as shown in § 72, declares that along the eastern border of New York, in the Southern district, the newer strata of the Hudson River slates dip eastward at high angles, apparently passing beneath the older ones, which in their turn seem to plunge beneath the ancient gneisses.

§ 110. This condition of things, (which applies alike to the Lower and the Upper Taconic rocks,) was described by Emmons in 1841, when he declared that "their present position is an inverted one;" the newer rocks, or those to the west, dip eastwardly beneath the older, or might even pass beneath them, provided they were prolonged in that direction." He supposed that the newer portions of the series might have been originally confined to the western parts of the area, and never have extended so far east as to cover the basal beds near the Primary

gneiss. He farthermore supposed the movement, which had given to the whole succession an eastward dip, had been accompanied by a series of dislocations, with uplifts on the eastern side of the faults. He remarks, in this connection, that "the force which breaks the continuity of the strata exerts its maximum power nearest the mountain-chain," and notes that in the Williamstown section (§ 104) not less than five distinct dislocations of this kind may be observed in a breadth of a few miles. (Agriculture, New York, p. 61, and Amer. Geol. II, pp. 43–46.) Such a condition of things is completely analogous to the great parallel faults, with upthrows on the south-east side, described by W. B. Rogers, and by Lesley, in south-western Virginia, by which the carboniferous rocks are made to dip to the south-east, apparently beneath much older strata.

§ 111. The Granville section of the Upper Taconic rocks, already noticed, is supposed by Emmons to have a total thickness of not less than 25,000 feet, but it is evident that dislocations like those just described, which may give rise to repetitions, must add greatly to the difficulty of measuring such a series of strata.

These Upper Taconic rocks are traced by Emmons southward through Washington, Rensselaer and Dutchess counties, and are said by him to cross the Hudson below Poughkeepsie, passing through Orange county, into New Jersey, and thence to Pennsylvania and Virginia. In the latter state a section of these rocks is described near Wytheville, and another from Abingdon, on the road leading to Taylorsville, Tennessee, in each of which both the Upper and Lower Taconic rocks are declared to be well displayed. (Amer. Geology, II, pages 61–61.)

§ 112. The reader will note that in the account of the Taconic system by Emmons in 1842, there is no description given of the great mass of strata which make the Upper Taconic, as defined by him in 1855. There evidently existed in his mind at this earlier date much uncertainty, which is reflected in his writings. Thus, in his report of 1842, the rocks of the Taconic system were declared to extend through the eastern counties of New York, from the Highlands, beyond which "they are found stretching through the whole length of Vermont, and into Canada, as far as Quebec." (loc. cit. page 136.) In a previ-

ous chapter, in the same volume, we are told, (page 121) under the head of the New York system, that a belt of deep red and purple shales, passing into a fine-grained gritty sandstone, extends throughout these same counties in New York "and onward through Vermont into Canada." No locality in Canada was indicated, but these slates and sandstones were referred to the Loraine shales, of which they were considered a local variation, unknown in the valley of the Mohawk; while a greenish chloritic sandstone or breccia, described as a typical Graywacke, (which is placed at the summit of the Loraine,) is said to be the material used at Quebec for the construction of the fortifications of the city (page 125.) Farther on in the same volume, the sandstones (Graywacke) of Addison, Vermont, as seen in Snake Mountain, and those of Charlotte in the same state, are described as gray, or reddish-brown, and sometimes, like their associated slates, as having a greenish chloritic coloring. These sandstones and slates of Charlotte are spoken of as belonging to a range extending from Columbia county, New York, to the Canada line, and as occupying a position immediately below the Medina sandstone, or at the summit of the Loraine shales; the limestones of the Chazy and Trenton appearing to dip beneath the Graywacke series. (Pages 280–282.)

§ 113. Near the city of Quebec, with the geology of which Emmons was familiar, there are, besides the ancient gneisses, two series of rocks; one the nearly horizontal strata of the New York series, including the Trenton, Utica and the overlying typical Loraine shales, (all of which were there recognized by Emmons); and the other, the highly inclined group of strata which consist in their upper part of red and purple shales, and are terminated by the greenish chloritic sandstones of Sillery, which are those used in the construction of the fortifications of Quebec. These rocks are traced from this locality south-eastward, to the frontier of Vermont, along the western base of the hills of crystalline rock, and there is nothing throughout the whole extension which resembles the quartz-rock or the limestones of the Lower Taconic series. It seems, therefore, impossible to come to any other conclusion than this,—that the Taconic rocks, which were by Emmons, in 1842, declared to extend from Vermont to Quebec, are the same with those which

he elsewhere, in the same volume, describes as rocks belonging to the summit of the Champlain division, and having the same distribution. This conclusion is further strengthened by the fact that what he described in 1855 as the Upper Taconic series has actually been traced from Vermont, along the line just indicated, to the city of Quebec, the vicinity of which affords a characteristic section of much of the series. The student of the works of Emmons will find in them other examples of apparent discrepancies and contradictions, which are, however, easily explained by the disjointed and fragmentary form of his writings; in which unity, method and literary skill are, unfortunately, wanting. These defects have contributed not a little to the undeserved neglect with which his very valuable contributions to American geology have hitherto been generally treated.

§ 114. In 1846, as we have already noticed, the gray, reddish-brown and greenish sandstones and slates of Addison, Charlotte, Burlington and St. Albans, (which, like the similar ones of Quebec, were, in 1842, referred in one chapter to the summit of the Loraine shales, and in another chapter apparently confounded with the Taconic,) were regarded as pertaining to the Calciferous sandstone. This was described as a formation protean in its aspects in this eastern region, and was traced, as we are told, throughout the state of Vermont and the eastern counties of New York, till it crosses the Hudson river a few miles above Newburg and passes, as an interrupted belt, through Orange county. (Agriculture, New York, pages 120–121.) It was not at this time clearly distinguished from the Taconic slates, upon which it was said to rest, and when later (in 1855) the chief part of these slates was raised to the rank of a distinct series, under the name of Upper Taconic, the greenish chloritic sandstones of this region were included therein. The red sandstone of Burlington was now declared to be Potsdam, though some of the beds associated with it were still included in the Calciferous. (Amer. Geol., II, pp. 88, 128.) Subsequent studies in this region help to explain this confusion, by showing that these rocks, whether called Loraine and Oneida, or Calciferous and Potsdam, are but parts of the Upper Taconic series, and are the same with those which

Mather, in the southern part of their extension, referred, in 1843, to a horizon nearly coinciding with the highest of those just named, namely, the base of the Ontario division, including the Oneida and Medina formations—the red slates being, according to him, above and not below the sandstones.

§ 115. Emmons, in his successive works, makes no allusion to his repeated changes of opinion with regard to these rocks, so that the student who has not, with critical care, followed their history in his pages, fails to find the key to the contradictions, both real and apparent, which they contain. In his "American Geology," (II, page 88,) in treating of the red sandstone of eastern Vermont, which is there spoken of as Potsdam, reference is made to "the error which has been committed" in regarding this rock as the Medina sandstone; leaving the reader to infer that the error was committed by some geologist other than the writer. No further reference is there made by Emmons to his earlier views, and his subsequent publications throw but little additional light on the Taconic system. In his report on the "Geology of the Midland Counties of North Carolina," (1856,) pages 43–72, will, however, be found some few details on the Taconic rocks in that region; and his "Manual of Geology" (1860) may be read with advantage in this connection.

§ 116. It is proper, in this place, to notice the views and the observations of the late Prof. C. B. Adams, who, in a communication to the American Association of Geologists and Naturalists, in 1846, after Emmons had declared the red sandstone of Vermont to belong to the base of the Champlain division, and to rest upon the Taconic slates, still held to the view that both of these rocks are included in the upper portions of the same Champlain division. Of the north part of Addison county, Vermont, he said: "One of the most conspicuous rocks of this region is a Red sand-rock, which Dr. Emmons regards as at or near the base of the New York series, but which overlies the Champlain division in the (descending) order of Red sandrock, Hudson River (Loraine) shales, Utica slates, Trenton limestone, and La Motte limestone. A section was exhibited of Snake Mountain, in which these rocks appear, by an uplift, with their relative positions unaltered. The two lower formations are identified by their appropriate fossils,

which occur abundantly; the Utica slate by its position and lithological characters; the Hudson River shales by the same characters, and by their upper member, which is an argillaceous limestone, containing the stinted forms of *Chætetes lycoperdon*, which are usual in this, the last period of the existence of the species. The Red sand-rock lies upon the last named rock, in actual contact, with a moderate easterly dip. The upper part of the section is repeated, in the line of strike, in several other localities, but one only, Buck Mountain, three miles north, has sufficient elevation and steepness to exhibit the lower part of the series."

§ 117. "The assertion which had been made (by Emmons) that there is a line of fracture high up the side of Snake mountain, above the Trenton limestone, was shown to be entirely unsupported by facts. Not only is there no evidence that such a line of fracture has brought up the shales from beneath the Trenton limestone, but the fossils in the upper member of the shales prove that the present is their original relative position. But these are the Taconic slates of the Taconic system. From its position it may therefore be inferred that the Red sandrock is more recent than any of the Champlain division. Its fossils afford less demonstrative evidence." Adams found a trilobite which he regarded as resembling *Conocephalus*, together with an *Atrypa*, and, the horizon of the crustacean not being then well known, referred the Red sandrock to "the period of the Medina sandstone and the Clinton group." (Proc. Amer. Association of Geologists, Boston, 1846; in Amer. Journal of Science, [2] V. 108.)

§ 118. The Red sand-rock of this region is, in its turn, overlaid by a series of limestones, which were noticed by Adams, and subsequently described more particularly by Prof. W. B. Rogers. In following the sections from the western base of Snake or of Buck Mountain, he declares that "we ascend through the various divisions of the Matinal series, from the Trenton to the top of the Hudson River group, * * * each marked by characteristic fossils, and all maintaining a nearly uniform eastern dip. Above the latter, we find a series of red and greenish and gray sandstones and shales, of great thickness, succeeded, where the exposures are unbroken, by arenaceous

and argillaceous reddish and gray limestones, alternating with beds of sandstone similar to that beneath. Stratigraphically considered, this series of beds occupies the position of the Medina group of New York, or its equivalent, the Levant series of Pennsylvania and Virginia. * * * In the prolongation of this belt of sandstones and limestones towards the north, as at Winooski Falls, near Burlington, the latter mass is seen to consist, in great part, of a purplish-white, fine-grained limestone, "which, towards the base, contains layers of reddish limestone, interstratified with red sandstone." No fossil remains were, by him, found in this limestone, which he regarded as probably "a peculiar development of the upper portion of the Medina group."

§ 119. The above extracts from a paper written by Rogers, and presented to the American Association for the Advancement of Science, in 1851, were again read by him before the Boston Society of Natural History, in 1860, on the occasion of the presentation of a paper by Prof. C. H. Hitchcock, which is thus resumed. "The two most interesting points in this connection were, that there is no foundation for what Mr. Emmons called his Taconic system (a mixture of the Silurian and Devonian); and that the Dorset limestone (his Stockbridge limestone) is newer than the Lower Silurian, and probably Upper Silurian or Devonian." (Proc. Boston Soc. Natural History, VII, 238.)

§ 120. Reverting now to Prof. Adams, we find that he had already, in 1846, in his communication just cited, advanced similar views to those of Hitchcock. The strata of the Lower Taconic series of Emmons occur, in Vermont, to the east of the rocks just described, and between them and the Green Mountains; and Adams conceived it probable that "the Taconic quartz-rock is a metamorphic equivalent of the Red sandrock." In a section from Lake Champlain to the Green Mountains, through Ferrisburg and Monkton, there seemed to be a gradual change in lithological characters, from the Red sandrock to the quartz-rock, which he ascribed to "the effect of igneous agency in the eastern part of the section." Inasmuch as the section was in large part concealed, however, "the identity of the Ta-

conic quartz rocks with the Medina sandstone was not positively affirmed."

§ 121. A similar agency, according to Adams, might also have changed the limestones which overlie the Red sandrock; and in support of this view, a section from Buck Mountain, through Waltham, into New Haven, was exhibited, to show it "somewhat probable that the Stockbridge limestone of the Taconic system is the equivalent of the calcareous rocks which overlie the Red sandrock, rather than of the lower limestones of the Champlain division, as has been commonly supposed." (Amer. Jour. Science, [2] V, page 108.) The allusion in this sentence is to the view of Mather, already explained, (§ 68) which had at that time been accepted by James Hall, H. D. Rogers, W. B. Rogers and other American geologists; who, almost without exception, rejected the Taconic system of Emmons, and regarded the Stockbridge limestone as occupying a position between the Potsdam sandstone and the Hudson River (Loraine) shales.

§ 122. The communication of Adams, above examined, embraced two distinct propositions: first, that of the Levant (or Medina) age of the Red sandrock and its overlying limestones, (subsequently included in the Upper Taconic); and, second, that of the conversion of this series, by igneous agency, into the granular quartz-rock and the granular limestone of the Lower Taconic, and the consequent Levant age of these latter. The second proposition, although accepted by Hitchcock in 1860, does not appear to have been supported by Rogers.

§ 123. We have seen that Mather regarded the crystalline strata of southeastern New York as altered or Metamorphic rocks of the Champlain division, (§§ 81-82,) and that he extended this view to the similar rocks of western New England, with which they are continuous. These gneisses and crystalline schists, which constitute the lower division of the Primitive series of Eaton, and were called Primary by Emmons, can be traced over the greater part of New England, and form the chief portion both of the Green and the White Mountains. Eaton, although familiar with the rocks of western New England, does not appear to have studied those of the White Mountains, nor had they attracted the attention of

Mather. In 1844, Messrs H. D. and W. B. Rogers, in an essay upon their geology, state that these mountains had previously been regarded as belonging to the "so-called primary periods of geological time." They however extended to them the notions of Mather, and suggested that the crystalline rocks of the region were altered paleozoic strata, possibly of the Matinal division, (Utica and Loraine,) but more probably belonging to the Levant division, which included the Oneida, Medina and Clinton formations of New York. The gneisses bore, in the opinion of these observers, some resemblance to the sandstones of the lower part of this division, and they also found, in certain beds among them forms, which were conceived to be the remains of crustaceans and brachiopods, of species belonging to the Clinton formation. (American Journal of Science, [2) I, 411). In 1847, (Ibid, V, 116,) the same observers announced that they no longer regarded these forms as of organic origin, but did not, however, retract their previously expressed opinion that the crystalline stratified rocks of the White Mountains are of paleozoic age.

§ 124. Charles T. Jackson, to whose labors the geology of New England is much indebted, published in 1846, his report on a geological survey of New Hampshire, in which he maintained, (in opposition to the opinion of the Messrs. Rogers,) that the White Mountains constitute an axis of Primary rocks, granite, gneiss and mica-schist, successively overlaid, both to the east and the west, by Cambrian and Silurian rocks. These, on the western side of the axis, in Vermont, have, according to him, been changed by the action of intrusive serpentines, and intrusive quartzites, which altered the Cambrian strata into the gneissic rocks of the Green Mountains, and converted a portion of the fossiliferous limestones of the Champlain valley into white marbles—the Lower Taconic limestones of Emmons. (Loc. cit., pages 160–162).

In the next chapter it is proposed to trace the history of geological investigation in Canada.

CHAPTER III.

HISTORICAL SKETCH, CONTINUED.

§ 125. Having given in the preceding chapter the history of geological investigation during the first half of this century, so far as regards the ancient rocks under discussion, from Virginia northward to the confines of Canada, we now proceed to a consideration of the labors of the Geological Survey of that country, the officers of which have continued the work of the American geologists already mentioned, and have greatly advanced our knowledge of these rocks. In this connection, also, will be discussed the geology of Lake Superior.

We have already seen (§ 51) that Eaton, as early as 1832, had recognized the existence of gneissic rocks like those of the Adirondack Mountains, extending from that region to the vicinity of Montreal, and also to Lake Huron and Lake Superior. We find, moreover, that Emmons, in 1842, had traced the rocks of the Champlain division from the valley of the lake of this name to Montreal and Quebec. The early work of Baddeley, Bigsby and Bayfield in Canadian geology deserves honorable mention in this connection, and the observations of the latter two, so far as they bear upon the questions before us, will be noticed farther on in the chapter.

§ 126. The Geological Survey of Canada was organized in 1842, at which time Mr. (afterwards Sir) William Edmund Logan was appointed chief geologist, and Mr. Alexander Murray his assistant. The views of Logan on the geology of Canada at that time are embodied in an official letter, accompanied by a preliminary report, dated December, 1842. These, however, were not published until 1845, when they appeared, with some explanatory foot-notes, in a volume, together with the report of the labors of Messrs. Logan and Murray for the year 1843.

§ 127. In the letter, and the preliminary report just alluded to, Logan distinguishes a series of "Primary and Granite rocks," elsewhere described as "a range of syenitic hills of a gneissic order," bordering the St. Lawrence on the north, and connected by "the very narrow isthmus of the Thousand Islands" with the similar rocks in northern New York. To the westward, these Primary rocks were said to form the northern shores of Lakes Huron and Superior, and to stretch along the north side of a great basin of "Transition rocks," chiefly limestones, occupying the St. Lawrence valley. Logan farther tells us, that from beneath the southern edge of the Transition trough, "there rises an important formation of pyritiferous clay-slate, * * which is widely spread over the Eastern Townships, south of the St. Lawrence." In the foot-notes to this preliminary statement, it was however said that these clay-slates were supposed, from farther investigations, to be of more recent origin than the Transition limestone, and "probably above, instead of below it, in geological position." Overlying these clay-slates were noticed fossiliferous limestones of unknown age, found on the river Famine, a tributary of the Chaudière, and on the river St. Francis, near Sherbrooke.

§ 128. Referring to the contorted rocks of Point Levis, opposite to Quebec, Logan was "inclined to the opinion that they come out from below the flat limestones of the St. Lawrence," though he added in a foot-note at the time of publication, (in 1845) that "the accumulation of evidence points to the conclusion that the Point Levis rocks are superior to the St Lawrence limestone." In this latter view of these rocks near Quebec, he had accepted the conclusions of Emmons, announced in his report published in 1842 (§ 65); while, as regards the clay-

slate formation,—supposed by Logan to be a prolongation of the Argillite formation of Eaton from eastern New York and Vermont,—he adopted the opinion expressed by Mather in his report of 1843 (§ 68).

§ 129. The published results of the geologists of New York and Pennsylvania were at this date familiar to Logan, as is made more evident in the first portion of his report of progress for 1843, published with the preceding, in 1845. In this he describes the various members of the New York series as traced northward through these States into the great Transition trough of the St. Lawrence, and remarks that "these fossiliferous formations, wherever they have been found in actual contact with the rocks beneath, appear to rest upon masses of the Primary order. But the geologists of New York consider that they have evidence of the existence of a series of non-fossiliferous sedimentary strata, in a more or less highly crystalline condition, of an age between the two." This referred to the Taconic system of Emmons, already at that time announced by him as occupying an intermediate position between the Primary and the fossiliferous rocks of the New York series (§ 67). Logan, however, proposed on account of "the considerable difficulties attending the question, * * * * to unite all the subjacent rocks, whether Metamorphic or Primary, and to class them under the latter denomination."

§ 130. Mr. Murray, in his report of progress for 1843, published in the volume just mentioned, noticed that some of the Primary rocks on the northeast shore of Lake Huron, and farther eastward, north of Lake Simcoe, present evidences of bedding or stratification, which led him to "consider the term Metamorphic as one of appropriate application to some of the rocks beneath the fossiliferous, and unconformable with them." He therefore designated this series (described by him as similar to those of the Thousand Islands) as "Primary and Metamorphic rocks."

§ 131. In the year 1845, Mr. Logan ascended the Ottawa river a distance of 150 miles from its mouth, to the head of Lake Temiscaming, exploring, moreover, some of its tributaries, and carefully studied the geology of the region, making

large collections. In the following year (1846) he, with the aid of Mr. Murray, explored in like manner the Canadian shores of Lake Superior. The labors of these two years contributed greatly to our knowledge of the older rocks, but the reports of them were not published, nor indeed completed, until 1847.

§ 132. In this connection a personal statement may perhaps be permitted, as serving to give weight and authenticity to the earlier lithological and mineralogical descriptions in these, and in subsequent reports of the Canada Survey, which have a historical importance in connection with the study of the older rocks. It was in February, 1847, that the present writer commenced his labors at Montreal, as chemist and mineralogist to the Geological Survey of Canada (after having previously, for some months, filled the same post in the Geological Survey of Vermont, then in progress under Prof. C. B. Adams). The publication of the reports of the Canada survey for 1845, having been delayed, he was thus enabled to examine and describe the various rocks and minerals from the region of the Ottawa, as well as those from Lake Superior. For the lithological and mineralogical notes and descriptions which occur in the reports for 1845 and 1846, and in the subsequent publications of the survey, during twenty-five years, the present writer is responsible, inasmuch as they were all written by him or under his supervision.

§ 133. In Logan's report on the geology of the Ottawa, published in 1847, the ancient crystalline rocks, which he had previously called Primary, were distinguished, in accordance with Mr. Murray's previous suggestion, (§ 130) as "belonging to the order which, in the nomenclature of Lyell, is called Metamorphic instead of Primary, and as possessing an aspect inducing a theoretic belief that they may be ancient sedimentary formations in an altered condition." This "Metamorphic series" was then described as consisting of a lower and an upper group, the former consisting chiefly of reddish and grayish syenitic (that is hornblendic) gneisses, much contorted and generally at high angles. These were succeeded by a series in which, it was said, "important beds of crystalline limestone become interstratified with the syenitic gneiss, and their presence constitutes

so marked a character that it appears expedient to consider the mass to which they belong as a separate group of metamorphic strata, supposed, from their geographical position and general attitude, to overlie the previous rocks conformably."

§ 134. A careful section of a portion of this "upper group," as it was then called, was given, accompanied by minute lithological descriptions of the gneisses of both groups, and of the crystalline limestones, together with the minerals both of the strata and the numerous veinstones occurring in them;—the results of a careful study by the present writer of the collections made in 1845. (Report for 1845, pp. 40–50.) In 1847 he spent some weeks in the field among the same rocks, and his report thereon will be found to contain farther details of their mineralogy and lithology (Report for 1848, pp. 125–138).

§ 135. This Metamorphic series, of two conformable groups, was described by Logan in 1845, as forming a great axis, crossing the Ottawa river, and separating the rocks of the southern trough of fossiliferous rocks, (the great Transition trough of the St. Lawrence and the lower Ottawa, already noticed) from a northern trough, the strata of which was discovered by him on Lake Temiscaming, on the upper Ottawa, resting upon the Metamorphic series. They were then described as consisting, in ascending order, of 1°, chloritic slates and conglomerates; 2°, greenish sandstones; 3°, fossiliferous limestones. The first of these were grayish and greenish slates, chloritic or finely micaceous, often very compact, traversed by seams of quartz, and sometimes holding pebbles and rounded masses of the subjacent gneiss. These strata had a moderate dip, and an estimated thickness of not less than 1,000 feet. Reposing on these slates were several hundred feet of greenish sandstones and conglomerates, in nearly horizontal beds, overlaid by 400 or 500 feet of light gray limestones, sometimes abounding in chert and interstratified with greenish shales. Many of the limestones were very fossiliferous, containing the characteristic organic forms of the Niagara limestone. A conglomerate, made up of the ruins of the underlying sandstone, formed the base of the limestone series.

§ 136. In the following year (1846) the work of Logan and of Murray on Lake Superior and its tributaries, added much

more to our knowledge of the older rocks. In his report, published in 1847, the former described the lowest rocks along the north shore of the lake as consisting of granite and syenitic (hornblendic) granite, "which appear to pass gradually into gneiss." Similar rocks were also observed by Murray in the Kamanistiquia and Michipicoten rivers. Resting upon these ancient rocks, and in many places enclosing pebbles of them, was a second series, described as consisting of chloritic, micaceous and talcose slates, sometimes epidotic, with interstratified beds having the characters of greenstone, and others of quartz-rock, the whole series much contorted, and dipping at high angles, with an east and west strike. Their thickness was estimated at several thousand feet, and they were observed by Logan at the mouth of the river Doré near Gros Cap, and at Thunder Bay, and also, by Murray, on the Kamanistiquia. The former declared that the "chloritic slates at the summit of the older rocks, upon which the Volcanic formations rest unconformably, strongly resemble those of Lake Temiscaming, and it appears probable that they will be found to be identical" with them. (Report for 1846, page 34.)

§ 137. The "Volcanic formations," above alluded to, are described by Logan, in the same report, as consisting of unerystalline sedimentary strata, interstratified with and overlaid by eruptive rocks, and were divided by him into a lower and upper group. The first of these was seen at Thunder Bay, resting, in a nearly horizontal position, upon the highly inclined chloritic slates, fragments of which entered into a conglomerate at the base of the lower Volcanic series.

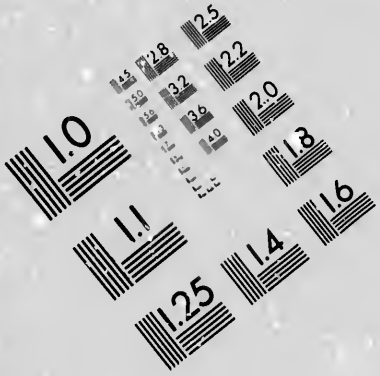
Overlying this conglomerate were beds of chert or hornstone, with calcareous layers, sometimes becoming impure limestones; the whole, higher in the series, accompanied with dark bluish argillaceous slates and argillaceous sandstones, intersected by dykes, and interstratified with layers of crystalline hornblendic trap; a mass of which, 200 or 300 feet in thickness, caps the lower group, estimated to have a total volume of 1,500 or 2,000 feet. These rocks are seen at Thunder Bay and westward to Pigeon river, forming the shores of the lake and the adjacent islands.

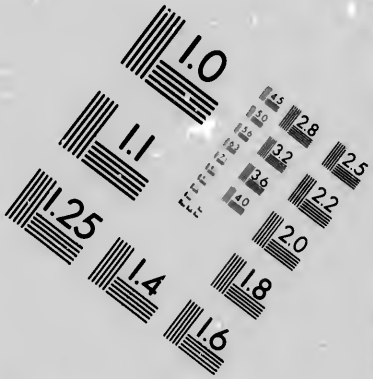
§ 138. Resting upon this lower group to the eastward, was

a series of red and white sandstones, and conglomerates, holding pebbles of jasper, chert and limestone, and having an estimated thickness of about 700 feet. These were succeeded by reddish white compact limestones, interstratified with calcareous shales and sandstones, and overlaid by reddish marls, making, in all, about 130 feet additional. "Succeeding these calcareous strata, after an interval of which the amount is uncertain," another series of red and white sandstones, with conglomerate layers, was met with. These were interstratified with layers of trap, often amygdaloidal; "and an enormous amount of volcanic overflow crowns the formation." Besides the bedded amygdaloids were great masses of highly crystalline trap, passing into well-marked basalt, together with vitreous traps having the forms of pitchstone and pitchstone-porphyry.

The thickness of this upper Volcanic group, on which were included the calcareous strata and the red and white sandstones beneath them, was estimated, as seen in various sections, at from 6,000 to 10,000 feet. (Report for 1846, pages 13–16).

§139. This series was found to the east of Thunder Bay, resting upon the rocks of the lower Volcanic group just described, beyond which it was recognized on St. Ignace and the other islands along Nipigon Bay, and, farther east, in Michipicoten Island, and on the mainland at Cape Gargantua, Pointe aux Mines, Mamainse and other places, in which the red sandstones, conglomerates and amygdaloids of the upper Volcanic group were seen to lie unconformably upon the ancient gneissic and granitic rocks. This series, in many parts of its distribution, abounds in native copper, and was by Logan regarded as identical with that of Isle Royale, then visited by him, and with the similar copper-bearing rocks of the southern shore of Lake Superior. As regards the age of the copper-bearing series, he conceived it to be older than the horizontal paleozoic sandstones found in the vicinity of Sault Ste. Marie, and cited with approval the opinion expressed by Haughton of Michigan, in 1841, that it was probably more ancient than the Potsdam of the New York series. The important bearing of these facts on the history of the Lake Superior rocks will be apparent further on.





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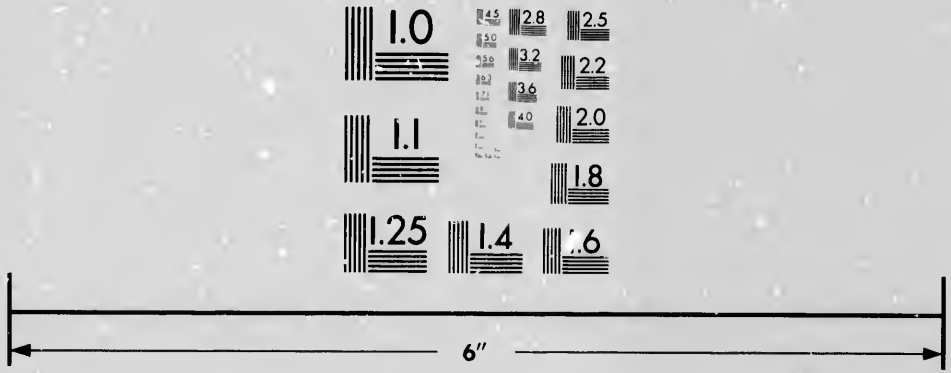

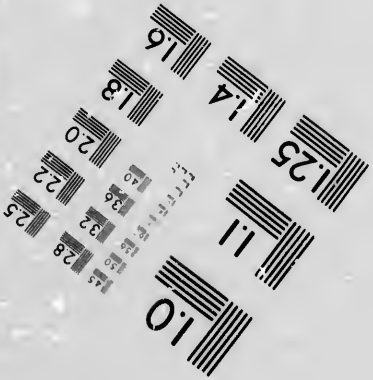

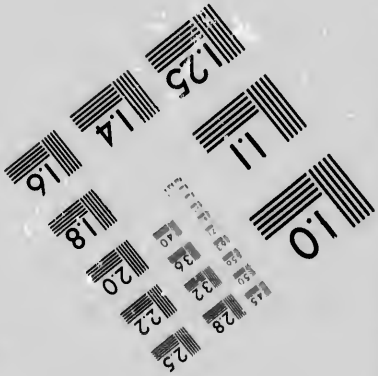

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§ 140. In the summer of 1847, Mr. Alexander Murray commenced the geological exploration of the north shore of Lake Huron, where, as is described in his report of that year, he found, resting upon granitic and gneissoid rocks, a great series of chloritic slates and conglomerates, with interstratified greenstones, quartzites and limestones. This intermediate series was described as forming the whole northern shore of the lake, and as unconformably overlaid by the lower members of the New York series of paleozoic rocks.

These explorations were continued by Mr. Murray in 1848 and 1849. The frequent occurrence of sulphuretted ores of copper having been noticed in the intermediate series of rocks, they had already attracted the attention of mining explorers, when, in 1848, the region was also visited by Mr. Logan, in company with the present writer.

§ 141. The reports of both Murray and Logan for 1848 contain much additional information respecting this series of rocks. The great likeness between these and the chloritic-slate formation, previously examined and described on Lake Temiscaming and Lake Superior, is however nowhere alluded to in these reports, though their identity was some years afterwards fully recognized in the official publications of the geological survey. In explanation of this, it must be said that Logan conceived these copper-bearing rocks of Lake Huron, notwithstanding their lithological dissimilarity, to be the geological equivalents of the so-called Volcanic formations, which he had previously described as resting unconformably upon the similar chloritic slates and greenstones of Thunder Bay on Lake Superior.

In his report for 1848, (page 20,) he attempts to compare the copper-bearing rocks of Lake Huron with those yielding native copper on Lake Superior. The greenstones of the former,—which he regarded, in accordance with the then universally received view, as of igneous origin,—were confessedly unlike the amygdaloids of Lake Superior; and the sandstones associated with these were very unlike the vitreous quartzites which, on Lake Huron, were interstratified with the crystalline greenstones and chloritic slates containing the pyritous copper ores of that region. But, in his language, "notwith

standing these differences, there are such strong points of resemblance, in the interstratification of igneous rocks, and the general mineralised condition of the whole, as to render their positive or approximate equivalence highly probable, if not almost certain."

§ 142. Much stress was laid by him upon the fact these two formations were found, in contiguous regions,—the chloritic and greenstone series on the north shore of Lake Huron, extending westward nearly to Sault Ste. Marie, and the amygdaloid series, with native copper, at the eastern end of Lake Superior,—both resting unconformably upon the ancient granitic series, and both overlaid conformably by the newer and horizontal sandstones, then regarded as the equivalent of the Potsdam of the New York series. The fact that the amygdaloid series further west, in Thunder Bay, had beneath it the dark colored argillites and sandstones, which in their turn rested unconformably upon a chloritic and greenstone series like that of Lake Huron, was strangely overlooked. That the great difference between these copper bearing rocks on the two lakes was, in some way, due to the action of supposed intrusive rocks, which had metamorphosed the one more highly than the other, was the view entertained by Logan for many years. This same view is well stated by Dr. J. W. Dawson, who, in 1857, published a detailed account of an examination of the cupriferous amygdaloids and conglomerates of Mamainse, and, accepting the view of Logan, (also adopted by Rivot,) that these were the geological equivalents of the Lake Huron series, expressed the opinion that while these latter "may have thus originally been similar to those of Mamainse, they have been far more altered, and are associated with the deep-seated crystalline products of volcanic agency, instead of with those that are superficial. Differences of this kind imply, however, no difference in age." Canadian Naturalist, vol. II, page 11).

§ 143. The observations of Mr. Murray on Lake Huron had already shown the existence of two unconformable series of crystalline stratified rocks, which were, in their turn, overlaid in discordant stratification by the nearly horizontal paleozoic strata, reposing sometimes on the older and sometimes on the

younger of the crystalline series. The former of these, consisting of granitic and gneissic rocks, with crystalline limestones interstratified in the upper portion, had been distinguished as the Metamorphic series, but this name was not less applicable to the overlying group of chloritic slates, with greenstones and quartzites. It was therefore proposed to give the older group a distinctive name, and inasmuch as these rocks form the hills on the north side of the St. Lawrence, to which Mr. Garneau, the Canadian historian, had already given the geographical name of Laurentides, "the distinctive appellation of Laurentian," proposed by the present writer, was applied to them in the Report of the Geological Survey of Canada for 1852, (page 9,) which was published in 1854.

§ 144. In the next year, (1855) there was published in Paris, under the name of "Esquisse Géologique du Canada, par W. E. Logan and T. Sterry Hunt," a small volume, with a geological map, intended to explain the geology of Canada as then presented at the great Exhibition at Paris.

In this little treatise the name of Laurentian was again employed to designate the ancient gneissic series, and at the same time, the name of Huronian was proposed by the present writer to distinguish the younger and unconformable series of crystalline rocks found on the shores of Lake Huron, and, also, the so-called Volcanic formations of Lake Superior, then considered as their geological equivalents. Henceforth the terms Laurentian and Huronian, which were used in the geological map accompanying the little volume, were employed by the Canadian Survey, and have since been generally adopted by geologists.

§ 145. Of these Huronian rocks it was then said that they "may be referred to the Lower Cambrian of Sedgwick;" inasmuch as I was then, as now, of the opinion that these rocks are identical with those crystalline strata in Caernarvonshire and Anglesea, which Sedgwick had, in 1835, designated as Lower Cambrian, and which Murchison still, in 1855, erroneously regarded as the lower part of the proper Cambrian series in an altered condition. (Hunt, Chem. and Geol. Essays, pages 353, 383.) Sedgwick had long previous to this placed these crystalline rocks at a horizon below the base of the Cam-

brian, but the authority of Murchison was, in 1855, unquestioned. Dr. Bigsby, in 1863, insisted that the typical Huronian rocks on Lake Huron, with which he had long before been familiar, were in no way to be confounded with the typical Cambrian of Wales, but belonged to a more ancient series. (Ibid, page 269, and Quar. Jour. Geol. Society, XIX, 36.)

§ 146. Meanwhile had appeared, in 1851, the elaborate report of Messrs J. W. Foster and J. D. Whitney, on the geology of portions of Lake Superior, including the south shore and Isle Royale. This was, up to that time, the most important and considerable contribution which had been made by the geology of our older rocks, Prof. Whitney having brought to the subject a wide acquaintance with the literature of geology and mineralogy. We give below his grouping and nomenclature of the rock-masses of the Lake Superior region, in accordance with the classification of Constant-Prevost. (Geology of Lake Superior, vol. II, page 2).

I. IGNEOUS; of various ages, divided into
  A. *Plutonic rocks;* consisting of Granite, Syenite; and Feldspar and Quartz-rock.
  B. *Trappean and Volcanic rocks;* consisting of Greenstone or Dolerite; Porphyry; Basalt; Amygdaloid; Hornblende and Serpentine rocks; masses of Specular and Magnetic Oxyds of Iron.

II. METAMORPHIC; belonging to the *Azoic system*, including Gneiss; Mica and Hornblende Slate; Chlorite, Talcose, and Argillaceous Slate; beds of Quartz and Saccharoidal Marble.

III. AQUEOUS; beginning with *Lower Silurian*, of which the members were, in ascending order: Potsdam sandstone; Calciferous sandrock; Chazy limestone; followed by the Trenton limestone, with its sub-divisions; the Utica slate, and the Lorraine or Hudson River slates of the New York series. (§ 64.)

Besides these three great classes there are included, under the name of PLUTO-NEPTUNIAN, those volcanic rocks which have been modified by water after their ejection, and thereby arranged in stratified deposits, such as trap-tuff and peperino, which were supposed to be largely represented in the copper-bearing formation of Lake Superior.

§ 147. Including the specular and magnetic iron ores of Lake Superior (and of other regions) among the igneous rocks, the authors discuss the view that they were deposited from water, which is declared to be inadmissible and inadequate to explain the geological relations of these ores. Nothwithstanding the banded structure of these deposits, as seen on Lake Superior, they were "disposed to regard the specular and magnetic oxyds of iron as a purely igneous product, in some cases poured out, but in other cases sublimed from the interior of the earth." Many of the deposits of pure ore, enclosed in crystalline strata, or traversing such in dykes, are supposed to "have risen up in a plastic state from below;" but when found impregnating crystalline strata, or interlaminated with them, their introduction was regarded as due to sublimation. The banded structure of the masses of ore, and its interlamination with chert, jasper and other matters, suggesting aqueous deposition, they supposed to be due "to the action of segregating forces." (Geology of Lake Superior, II, 68.)

§ 148. The Azoic system, as defined by Foster and Whitney, included both the older gneissic or Metamorphic series of the Canada survey (subsequently named Laurentian,) and the newer and unconformable crystalline series afterwards called Huronian. This, as developed on the southern shore of Lake Superior, included besides chloritic and talcose schists, the great deposits of iron ores just referred to, masses of greenstone, together with dark colored compact serpentines, and quartziferous porphyries; all of which were regarded as being of igneous origin, and as intercalated in the metamorphic schists of the Azoic system.

The copper-bearing series of the region, including the amygdaloids, inter-bedded traps, and conglomerates, was however referred to a more recent period, being regarded as forming a portion of the Potsdam sandstone.

§ 149. An instructive section given by Foster and Whitney (Vol. I, page 66) near the eastern end of Keweenaw Point, from Copper Harbor southward to Lake Labelle, traverses, in the northern portion, two principal ranges of bedded amygdaloid and granular trap with conglomerates and native copper. To the south of this, a third parallel east and west belt of so-called

trap, constitutes the Bohemian Mountains, described as composed of "a vast crystalline mass, forming an anticlinal axis, flanked on the north by the bedded traps and conglomerates, and on the south by sandstones with conglomerates." This southern range is said to be widely unlike both in structure and composition to the traps of the northern ranges, being a dark-colored fine-grained greenstone, made up of labradorite and green hornblende, sometimes with an admixture of chlorite. It is distinctly stratified, and dips to the N. W. at an angle of 65° or 70°. At the southern base of the range is a broad belt of fissile chloritic rock, which is, in parts, an admixture of labradorite and feldspar, with disseminated crystals of magnetite and grains of copper-pyrites.

§ 150. Throughout this southern range native copper is wanting, but numerous veins of quartz, sometimes with calcite and chlorite, are met with, carrying sulphuretted copper ores. In the eastern part of the Bohemian range (according to Rivot) the greenstone is replaced by a jasper, which forms great masses, and makes the summit of Mount Houghton. This rock is supposed by Foster and Whitney to have resulted from the alteration, by the intrusive trap, of the adjacent sandstones, and is described as in some parts red, occasionally banded and compact, with a sub-conchoidal fracture; elsewhere it includes feldspar and chlorite, and shows lines of stratification.

§ 151. A similar red banded jasper-rock occurs in the Porcupine Mountains, a range of hills near the southern shore of the lake, rising between Carp and Iron rivers, where a large area, designated in the geological map of Foster and Whitney, as composed of "igneous" rocks, is described by them as consisting of jasper and quartzose porphyry. The highest parts of these hills are said to be composed of a compact red jasper, sometimes banded, and at other times mingled with grains of white quartz. It "sometimes shows a gradual passage into quartzose porphyry, with occasional imbedded crystals of feldspar." Such a porphyry forms very large masses on the head-waters of Iron river, where it is brick-red in color, and contains small crystals of white feldspar, generally with "rounded grains of vitreous quartz found distributed with the feldspar through the jasper base." Other varieties are described with

red feldspar crystals. This rock was regarded by the authors as an eruptive mass, and said to include fragments of older rocks. (Geology of Lake Superior, I, 65–70). The banded structure of some of the jasper of Mount Houghton was regarded by them as due to the original stratification of the sedimentary deposits, while that of the banded jasper of the Porcupine Mountains was declared (Ibid. II, 68) to present complex flexures, which "bear no mark of having been the result of original stratification;" there being no actual line of separation between the lighter and darker bands. We shall again refer to these jaspers and porphyries.

§ 152. In 1854, and again in 1855, Prof. Rivot, of the Ecole des Mines of Paris, visited the mining-region of Lake Superior, and described his observations in two elaborate memoirs in the *Annales des Mines* for 1855 and 1856 (5me. série, vols. V and X). We have already made use of his statements in speaking of the Bohemian Mountains. Rivot recognized in this region, besides the ancient granitic and syenitic rocks, which he regarded as eruptive, a vast series of chloritic and hornblendic schistose rocks, which, according to him, pass by insensible gradations into the massive greenstones found interstratified with them. Hence he rejected entirely the notion of the igneous origin of the greenstones, described by him as consisting chiefly of labradorite and hornblende, which were conspicuous in the hills of the Bohemian range already noticed, as well as in the Huron Mountains and near Marquette. The cupriferous amygdaloids and bedded traps of the more northern ranges in the Keweenaw peninsula were supposed by Rivot to belong to the same series as the greenstones found with the chloritic and hornblendic schists mentioned above, and to pass into them by gradations.

§ 153. Rivot thus rejected entirely the notion of the eruptive or volcanic origin of the amygdaloids and bedded traps of the cupriferous formation, maintaining that they were of metamorphic origin, and in fact that these, as well as the whole series of greenstones with chloritic and hornblendic slates, serpentines, jaspers and iron ores, in the Huron and Bohemian Mountains, had resulted from the more or less complete alteration of ferruginous slates and and sandstones "by some un-

known agent." The whole of these strata were by him supposed to be intercalated in the lower part of the paleozoic series, and he did not apparently recognize any discordance of stratification between the preceding rocks and the superior sandstones of the region. He noticed that in the greenstone and chloritic series of the Bohemian range (and elsewhere) copper was found in veins, in the form of sulphuretted ores, but he believed that these veins were in some cases continuous with those which, in the amygdaloid belts to the northward, carried metallic copper.

§ 154. Rivot was familiar with the results of the Canadian survey, and in his memoir of 1856 gave an analysis of the *Esquisse Géologique*, already mentioned, citing the names Laurentian and Huronian. He there states more distinctly than in his first memoir his view of the relations of the various rocks, and declares that "in immediate contact, and apparently with the granite, are found rocks evidently metamorphic, mica-schists, hornblendic schists very analogous to traps, quartzites and jaspers. At a certain distance, and above these, are the traps, conglomerates and sandstones, the stratified arrangement of which is very evident. It is not possible, at least on the American shore, to separate the traps from the other Silurian rocks." On the other hand, he describes traps as passing into well characterized metamorphic schists, and declares them to be "so connected with the metamorphic rocks, referred by Mr. Logan to the Cambrian (Huronian), that it is not possible to separate the two. These appear as the last term of the metamorphic action manifested at the contact of the granite, of which action the granite itself may perhaps represent only the highest development." The discordance noticed by Logan at Thunder Bay between the crystalline schists and the overlying series of argillites and sandstones with traps, Rivot thought might only be a local phenomenon, "to be explained by movements due to the neighberhood of the granite."

§ 155. The granites of this author were the granitoid rocks of the Laurentian system, which he elsewhere described as "important masses of granite, syenite and diorite, which seem to have traversed and disturbed" the more schistose feldspathic, micaceous and hornblendic rocks, and the crystalline limestones

of the Laurentian. In the bedded trappean rocks of the copper bearing series he, however, failed to recognize any eruptive masses, and found none of "the dykes of trap or diorite" noticed by Logan in this series on the north shore of the lake. The granites and related rocks seem to have been the only masses in the region to which Rivot assigned a plutonic origin.

§ 156. The observation of Rivot regarding the origin of the beds of rounded pebbles found between ridges of trap at Keweenaw Point deserves notice in this connection. They were, according to him, "due to the decomposition, by atmospheric agents, of the ancient conglomerate." The present writer, from his observations on the north shore of the lake in 1872, arrived at the same conclusion. At Mamainse, interstratified with the traps, are beds of conglomerate made up of large and small rounded masses of granite, red and gray Laurentian gneiss, chloritic schists and greenstones from the Huronian series, and tender mica-schists and gneisses having all the characters of the Montalban, together with masses of red quartzose sandstone, the whole cemented by white cleavable calcareous spar. The solution of this has reduced large portions of the conglomerate to loose pebbles, which form the lake shore.

§ 157. It thus appears that Rivot, while adopting, with regard to these rocks, a view the very opposite of that maintained by Logan, Foster and Whitney, and Dawson,—inasmuch as he denied the eruptive origin alike of many of the crystalline greenstones of one series and of the bedded granular traps and amygdaloids of the other,—was led to agree with Logan, and with Dawson, in assigning the two series to one geological horizon, and in regarding their mineralogical and lithological differences as due to variations in the degree of alteration. This extreme extension of the doctrine of metamorphism, which began to find favor with other geologists about the same time, was the natural reaction from the no less extreme plutonism which had hitherto prevailed, and marked the beginning of a revolution in geological theory.

§ 158. In 1857, Prof. J. D. Whitney published in the American Journal of Science ([2] XXIII, pp. 305–314) a review and criticism of the Laurentian and Huronian systems of the Canada geological survey. He therein asserted that "there is

no evidence, either lithological or stratigraphical, for separating the rocks of Lake Huron from those which occur farther east, and which are classed by Mr. Logan as Laurentian." Both of these, Whitney had included in his Azoic series, which he declared to consist, alike on the north and south shores of Lake Superior, "of talcose and hornblendic slates, and gneissoidal quartz-rock, resting on a granitic and syenitic nucleus."

§ 159. As regards the cupriferous series of the north shore of Lake Superior,—the upper division of the Volcanic formations of Logan,—he confirmed the opinion of the latter, that it was identical with that of the south shore. He had himself examined the trappean series in Nipigon Bay and the island of St. Ignace, and found its geological structure identical with that of Isle Royale and Keweenaw Point. (Geol. Lake Superior, II, 115.) The dark-colored argillites, cherts and sandstones of Thunder Bay, which Logan made the lower division of his Volcanic formations, represent, according to Whitney, only "a local variation in the composition," analogous to "the dark-colored and highly fissile beds of the Montreal, Presque Isle and Iron rivers of the south shore, which pass gradually into the usual red sandstone upwards and downwards." From the examination of this series, as developed in the south shore, he was "unable to see any reason for separating the cupriferous range from the sandstone which flanks it on either side."

§ 160. Whitney farther declared that "the native-copper bearing series of the north and south shores of Lake Superior cannot be separated from the Potsdam sandstone with which it is associated; neither is there any reason whatever for placing it in the same line with the rocks of the north shore of Lake Huron. These latter, as well as the great mass of crystalline rocks to the north and east, in Canada, are identical in position and lithological character with the series described by Mr. Foster and myself under the name of the Azoic system, and which cover so large an extent of territory in Michigan, Wisconsin and Minnesota." The rocks of this system, according to Whitney, underlie directly the trappean copper-bearing series, alike on the north and south shores of Lake Superior.

§ 161. The reasons of these opinions were given at length in the paper quoted, and need not be discussed here. The ver-

dict of later investigations has confirmed the previous determinations of the Canadian survey, both as to the existence of two distinct and unconformable series in the Azoic system of Whitney, and the unconformable infra-position of the trappean copper-bearing series to the so-called Potsdam sandstone of the region.

In his other principal point, however; namely, his objection to Logan's early attempt to establish a parallelism between the upper crystalline schists of Lake Huron and the trappean or Volcanic copper-bearing series of the north shore of Lake Superior, Whitney has been fully justified. He pointed out that the latter had been declared by Logan to rest unconformably, in Thunder Bay, on a formation of crystalline schists, and these, according to Whitney, were the precise equivalents of those of Lake Huron,—which had been by Logan compared with the overlying trappean series. There was, in fact, no good reason for this view of Logan's,—in which, however, he had, as we have seen, been followed both by Rivot and by Dawson,—and in the latter publications of the geological survey of Canada, the trappean series was, in accordance with the view of Whitney, separated from the Huronian, but, at the same time, from the overlying sandstones.

§ 162. In the years following 1849 no further attention was given by the Canadian survey to these rocks on Lake Huron or Lake Superior, until in 1854–1858, when Mr. Murray made his extended and careful geological and topographical surveys of the northeastern tributaries of Lake Huron and the region eastward. These explorations furnished many details of the Laurentian and Huronian series, the results of which are set forth in the annual reports for the years mentioned. From 1858 to 1863 no annual reports were published by the Canadian survey, but the results of explorations during this time were embodied in the volume of the Geology of Canada, published in 1863; in the Atlas and its accompanying text, which appeared in 1865; and in the larger geological map, (§ 44) published in 1866. In all of these the name of Huronian was restricted to the upper crystalline series of Lake Huron and the similar rocks on Lake Superior, where their distribution had been carefully studied by Mr. Murray in the years 1859 and 1860.

§ 163. In the Report on Lake Superior, in 1846, an area of these crystalline schists had been described at the mouth of the river Doré, and their presence had been noticed in Thunder Bay and on some of the tributaries of the lake. Murray found, in addition to these, a large extent of Huronian rocks in Goulais and Batchewanung Bays, (which were mapped in the Atlas,) traced them at intervals along the shore westward, found a still larger area of these rocks from the mouth of the Pic to the Steel river, extending far into the interior, and studied their distribution in the vicinity of Thunder Bay, as is shown in the Atlas, on the large map, and in the Geology of Canada (page 63). He moreover satisfied himself, by comparative studies on the south shore of the lake, that these Huronian rocks were identical with the schistose crystalline rocks of Whitney's Azoic series, as seen at the iron-mines in the vicinity of Marquette. (Ibid, page 66.)

§ 164. The Volcanic formations of the north shore of Lake Superior, now separated from the Huronian (which was sometimes distinguished as the Lower Copper-bearing series) were described in the Geology of Canada under the name of the Upper Copper-bearing series of Lake Superior, and divided, as before, into a lower and an upper group or division, (§ 137) no additional details as to its geology or mineralogy being given. The rocks of the upper division, which alone had been traced to the eastward of Black Bay, were described as having an east and west strike from the west end of the lake to the east of Michipicoten Island, a distance of 300 miles. This, along the eastern border of the lake, was exchanged for a strike nearly north and south, the amygdaloid and conglomerate rocks of Mamainse and Point aux Mines having a marked dip to the westward. This change in the strike is apparent for nearly 100 miles along the eastern shore, and in the vicinity of the nearly horizontal sandstones of the region, from the undisturbed attitude of which Logan argued, with much reason, that the sandstone must belong to a newer formation, overlying unconformably the Upper Copper-bearing series. This coincided with the early opinion of Haughton. (§ 139.)

§ 165. These nearly horizontal sandstones had hitherto been regarded as of Potsdam age, but the similar sandstones to the east of Sault Ste. Marie were found by Hall, and by Murray, to be conformably overlaid by a series of limestones holding the organic remains of the lower divisions of the Trenton, with indications of the Chazy at the base; while still further east these limestones, without the intervention of the sandstones, rest directly on the older crystalline strata, the Calciferous sandrock and the Potsdam sandstone of the New York series being absent. It was therefore suggested by Logan that the sandstone might itself represent the Chazy, in which case the unconformably underlying copper-bearing series, with its amygdaloids and bedded traps, "might reasonably be considered to belong to the Calciferous and Potsdam formations." (Ibid, pages 86–87).

Resting upon the sandstone on the south side of Kewenaw Point, Foster and Whitney found a magnesian limestone which also, according to Hall, contains the organic remains of the base of the Trenton. The sandstones of the region have moreover yielded a species of *Lingula* at Tequamenen Bay, and at Marquette a cast of *Pleurotomaria*, the species of neither of which could not be satisfactorily identified. (Hall, 16th Report to the Regents of the University of New York, pages 214–215; Geology of Canada, page 86, and Report of the Geological Survey of Canada, 1866–69, page 475).

Of the farther development of Logan's new suggestion as to the age of the trappean copper-bearing rocks, which led him, in a later chapter of the Geology, (1863,) and in the Atlas, to refer them to what he called the Quebec group, we shall treat, after having described the progress of geological investigations in the province of Quebec. We shall then also consider the opinion advanced by certain investigators, at an early period in the study of the geology of Lake Superior, that the copper-bearing rocks are of Mesozoic age.

§ 166. We have already seen that the sedimentary rocks from the eastern shore of Lake Champlain had been declared by Emmons, in 1842, to extend north-eastward as far as Quebec, where were displayed the upper members of the Champlain division, at times confounded by him with the rocks of

the Taconic system (§ 112–113). Along the south-eastern border of these sedimentary strata rises a chain of hills of crystalline rock, which are the prolongation of the Green Mountains of Vermont, and are sometimes known in Canada as the Notre Dame range. This belt has a breadth of about thirty miles on the frontier of Vermont, which, on the St. Francis, is reduced to about twelve miles, but in its extension to the north-east, where it is intersected by the Chaudière, broadens again to its former width. The range attains in the hills of Sutton, Orford, Ham and Cranbourne, heights of more than 3,000 feet above the sea, but a little to the east of the Etchemin river, and south of the island of Orleans, disappears beneath the sedimentary rocks, after a course of about 150 miles from the frontier of Vermont.

§ 167. These crystalline rocks reappear again to the northeast, after an interval of more than 250 miles, within twelve miles of the south shore of the St. Lawrence, between the rivers Matanne and Ste Anne in Gaspé, where they form a narrow belt similar to the Notre Dame range, known as the Shickshock Mountains, which rise to the height of 3,000 feet and extend for a distance of about sixty miles in a direction east-northeast. Beyond the Shickshock Mountains, to Cape Rosier, the northeast point of the peninsula of Gaspé, a distance of nearly ninety miles, the country in their range is occupied, like the interval between the Etchemin and Matanne rivers, by uncrystalline sedimentary rocks.

This account of the distribution of the rocks of the Green Mountain belt to the northeast is rendered necessary from the fact that the geological maps of Canada, hitherto published, fail to make any distinction between the crystalline rocks and the sedimentary strata, which are found in the strike of these to the northeast, and moreover bound them on the north and west. These two unlike classes of rocks were by Logan supposed to be one and the same series in different mineral conditions, and in accordance with this view the maps are so colored that it is made to appear as if the crystalline belt of the Green Mountains were continuous to the northeastern extremity of the continent.

§ 168. To the east and south, these crystalline rocks are overlaid (generally with an intervening series of argillites) by fossiliferous limestones belonging to the Silurian, which are traced from the valley of Lake Memphramagog northeastwards to the extremity of Gaspé, and in their northeastern extension are overlaid by a great mass of Devonian sandstones and shales, generally called the Gaspé sandstones, which pass beneath the coal-basin of New Brunswick. These newer rocks, where the crystalline schists are absent, rest unconformably upon the older sedimentary strata. The pyritiferous clay-slate formation, previously declared to exist on the southeast side of the St. Lawrence, (§ 127) included the unlike argillites of the two sides of the crystalline belt, as well as some of the more schistose portions of the latter.

§ 169. The older and greatly disturbed sedimentary strata, which, as already indicated, bound to the west and the north the crystalline rocks of this region, are a prolongation of the Upper Taconic rocks from western Vermont, and are themselves limited to the northwest by strata belonging to different members of the Champlain division. These are traced from Lake Champlain along the Richelieu river, and thence to the northeast, occupying both sides of the St. Lawrence, to the vicinity of Quebec, and, unlike the sedimentary belt to the east and south of them, are comparatively undisturbed, and nearly horizontal. A transverse section from the Laurentides across this part of the St. Lawrence valley, traversing the Notre Dame range to the valley occupied by Lake Memphramagog and the upper part of the river St. Francis, gives essentially the same geological succession as one from the Adirondacks across Lake Champlain and the Green Mountains to the Connecticut valley, except that the characteristic quartz-rock and granular limestone of the Lower Taconic, are scarcely, if at all, represented to the north of the Vermont frontier.

§ 170. It was in 1847 that Sir W. E. Logan, accompanied by the present writer, began the study of the rocks of this region, from Lake Champlain to the vicinity of Quebec, a work which was continued during a part of the summer of 1848. The results of these two years of labor were resumed in the Report of 1847, the publication of which was retarded until 1849, in or-

der to present more complete results, as is explained in the preface to this Report, and also in the Report of 1848, (page 6) published in 1850. A statement of the conclusions reached at that time with regard to the geology of Canada, including the region in question, will be found in a paper read by the present writer before the American Association for the Advancement of Science at Cambridge in 1849, and published in the American Journal of Science for January, 1850. ([2] vol. IX, pp. 12–19.)

§ 171. The belt of sedimentary strata, already described as bounding, on the west and north, the highly inclined crystalline rocks of the Notre Dame range, was found to consist chiefly of argillites with sandstones and conglomerates, including some masses of limestone, the whole in a greatly disturbed condition, and was correctly recognized by the Canadian survey as the prolongation of the Argillite and Graywacke series of the east side of the Hudson River.

In the Report for 1847, (embodying the results of 1848,) the views of Matter, already set forth (§§ 68–73), were adopted, together with those of Emmons, as already defined (§§ 65, 112, 113), and these rocks in Canada were referred to the upper portion of the Champlain division, under the name of the Hudson River group, and to the Shawangunk or Oneida of the succeeding Ontario division. The limestones of Phillipsburg, on Lake Champlain, the only fossiliferous strata then known in this belt, were regarded as of Trenton age.

§ 172. The crystalline rocks of the Notre Dame range were at the same time described as including clay-slates, micaceous, talcose, and chloritic schists, often with much epidote, quartzites, ferriferous dolomites and magnesites, steatites and serpentines, with massive diallagic, hornblendic, pyroxenic and feldspathic rocks; the whole associated with beds of magnetite, red hematite, titanic and chromic iron, and with sulphuretted ores of copper and native gold. The serpentines were shown to be banded interstratified masses, occupying, like the steatites and dolomites, a determinate place in the stratification. Two sections were then made across the belt, the one, a few miles north of the Vermont frontier, and the other, on the St. Francis river, of both of which detailed accounts were given. The

strata were shown to be highly inclined, and affected by numerous sharp undulations, the directions of which conformed with that of the mountain chain.

§ 173. The rocks of the Notre Dame range, it was said, "though stratified, are highly crystalline," but, it was maintained, "are to be considered not Primary, but Metamorphic." (Report of 1847, p. 30). They were regarded, in accordance with the views of Mather, (§ 80–81,) whose Report on the Southern district of New York was at that time carefully studied by the Canadian Survey, as having resulted from the alteration of the strata of the Hudson River group, which were supposed, at certain points along the line of contact between the two, to exhibit evidences of a gradual passage from the uncrystalline sediments to the crystalline schists. In summing up the facts detailed in elucidation of the structure of the Notre Dame range, designated as "the Green Mountains in their Canadian prolongation," the conclusion was reached that "the whole of the Green Mountain rocks, including those containing the auriferous quartz veins, belong to the Hudson River group, with the possible addition of part of the Shawangunk conglomerates." (Ibid, page 57.)

§ 174. The section along the St. Francis was continued from Sherbrooke southeastwards across the limestones of the valley, and thence to Canaan, in the northeastern corner of Vermont. The rocks were described as soft argillaceous, micaceous and calcareous schists, highly pyritiferous, succeeded by harder micaceous and quartzose strata, often with garnets and chiastolite, associated with beds containing black hornblende, and with granites. The latter were regarded as intrusive, which is true of a portion of the granitic rocks of the region. These strata were found to be highly inclined, with a prevailing inclination to the north-west, the latter part of the section forming a bold range of hills, in which the Connecticut and Chaudière rivers take their rise. No detailed examination was made of that part of the line of section from the limestones of the valley of Lake Massawippi to Canaan; the description of it given in the Report for 1847 having been taken from the notes made by Logan during a journey across the region as early as 1842. He however ventured, in accordance with the

views which had been advanced by Mather and the Messrs. Rogers, (§ 123) to assign these rocks to a higher geological horizon than the Green Mountains, and while the whole of the intervening calcareous strata were supposed to be Silurian, to put forth the suggestion that the mica-slates, with hornblendic, gneissic and granitic rocks, were perhaps of Devonian age, being "a part of the Gaspé sandstones in an altered state." (Report of 1847, pages 55–58).

§ 175. During the year 1849, the investigation of the Notre Dame range, and of the disturbed sedimentary belt along its western and northern boundary was continued, the latter being examined at various points from the northern extremity of Lake Champlain as far as the vicinity of Quebec, and thence along the northern shore of the St. Lawrence for about 130 miles, to the Temiscouata portage, a road leading to the lake of that name. The results of these investigations are set forth in the Report for 1849, published in 1850 (pages 31–64). Logan was aided in this field-work by Murray, and by the present writer. (Ibid, pages 6, 73.)

In describing the general distribution of the rocks along the south shore of the St. Lawrence, we have already made use of this exploration, and also of that of 1844. In this latter report Logan had given (pages 17–30) the results of his examination of this coast from Cape Chatte, a point a little farther east, to Cape Rosier at the extremity of the peninsula of Gaspé, and had also described the newer limestone and sandstone-formations lying to the southward, (§ 168) which were then designated the Gaspé limestones and the Gaspé sandstones (pages 31–66).

§ 176. The opinion was expressed in 1844, that these coastal rocks, or at least a portion of them, are "the equivalent of a part of the Hudson River group of the New York geologists" (page 21). It was afterwards clearly apparent that they were similar to those found along the coast between the Temiscouata road and Quebec, and to the belt now traced from Quebec to Lake Champlain. These, as we have seen in the Report for 1847, were also referred to the Hudson River group, regarded as belonging to the upper part of the Champlain division of the New York series, and in the same Report (page 58) reference

was made to "the continuous run of the recognized rocks of the Hudson River group from Lake Champlain, along the south side of the St. Lawrence, to Cape Rosier." In the Report for 1849 (page 18) it was again mentioned that "a formation contemporaneous with the Hudson River group, superior to the Trenton limestone, extends along the south side of the St. Lawrence from Point Levis (opposite Quebec) to Cape Rosier." The continuity of this belt of sedimentary rocks, along the east side of Lake Champlain, with the similar rocks to the east of the Hudson—the Argillite and Graywacke series of Eaton—had already been established by Emmons and by Mather, as shown in the preceding chapter.

§ 177. The observations of Mather and Emmons as to the singularly disturbed and often inverted attitude of these strata in the regions just mentioned were abundantly confirmed by the officers of the geological survey of Canada. The belt between Lake Champlain and the Temiscouata road is described as presenting "a multitude of anticlinal axes, over which, in succession, the strata bend in sharp plications, often leaning over to the northwest, giving the semblance of a nearly constant dip to the south-east, at high angles. These folds are so numerous, and frequently repeat the measures several times in so short a distance, as to destroy confidence in every endeavor to estimate the thickness of the different divisions of the deposit; and the want of knowledge of the true thickness, on the other hand, renders it uncertain, in any particular case under examination, whether all the folds affecting a set of strata have been correctly ascertained. The main undulations can often be followed for considerable distances by means of the geographical distribution of contorted masses of the sub divisions, but unless a connection or relation with regard to each other is followed out among these undulations, it is somewhat difficult to determine whether a form that may be subject to consideration is synclinal or anticlinal." (Report for 1849, pp. 31–32.)

§ 178. An illustration of this inversion of strata is seen in the Report for 1847 (page 24), where, in Granby, not far to the north of Lake Champlain, the red and green sandstones of the series in question are said to be folded in a great overturned

synclinal, in which the strata, on both sides of the basin, dip to the southeast at angles varying from 45° to 80°.

Still more remarkable examples of this are shown in the Report for 1844, in the account of the same belt on the south shore below Quebec, where it is said that the rocks "as they come out on the St. Lawrence exhibit a very contorted condition. The flexures are numerous, and some of them are so violent that serious inversions of the strata sometimes present themselves, and it is frequently very difficult to determine whether the mass under inspection be a new member of the deposit, or a repetition of one previously noted." (Report for 1844, page 18.)

§ 179. Numerous examples of this are given, one of which is on the east side of the Rivière Pierre, where the summit of the hill shows an overturn dip, and the strata in the whole section appear to be arranged in the form of a very flat **S**. Farther down on the coast * * * there are evidences of an overturn dip, * * * and a little under two leagues above Cape Magdalen, and about the same distance from Gros Mâle, the apex of the flexure connected with it comes out upon the shore. The direction of the anticlinal axis appears to be N. 65° W., magnetic, and proceeding from it upwards along the beach the strata, presenting at first a north dip of 20° to 40°, gradually become vertical; further on they overhang; still further the overturn increases, and the beds, becoming flat, with the bottom upwards, in this inverted position, roll farther over, and for a short distance slope slightly northward. From this, however, they recover, after no great interval, but finally in Gros Mâle bluff, they exhibit a short twist, occupying about twenty feet in the upper part of the cliff, in which, after returning to an uninverted north dip, they are again canted over to a nearly horizontal position, with the bottom upwards. The inverted beds examined extend upwards of five miles along the shore, and though the twists in the north side of the anticlinal, which roll them over to an upside-down *north* dip, are short, and therefore do not produce so important a result as the simple overturn *south* dip, they serve to illustrate the complication of the strata, and the difficulty of disentangling them in

endeavoring to follow out the order of superposition." (Ibid, pp. 23–24.)

§ 180. The strata in this disturbed region, below Cape Chatte, were described as consisting of great masses of sandstone, the vertical beds of which, by the action of the sea-waves, are wrought into upright columns, known to the navigators as Pillars, for which reason these rocks were called, in the Report, the Pillar sandstones. These sandstones, which are greenish in color and often conglomerates, holding pebbles of quartz and others of black shale, were found to be associated with bands of red, and more rarely with black argillaceous slates. Another portion of the series consisted of gray calcareous sandstones and gray limestones, sometimes oölitic in structure, together with conglomerates composed chiefly of limestone pebbles, interstratified with green and black argillites. Other portions presented thin-bedded limestones with gray sandstones and black shales holding graptolites.

§ 181. In the Report for 1849 an attempt was made to establish the succession of these rocks "in ascending sequence from the Trenton limestone and Utica slate." They were then divided into five groups, as follows:

1. Dark gray clay-slates, with gray thin-bedded sandstones, often calcareous, and with gray limestones, both weathering yellowish-brown. This division holds shells and graptolites, and appears to be terminated by bituminous shales and black limestones.

2. Gray, green and red shales, with thin calcareous layers and bands of calcareous conglomerate.

3. Hard gray sandstones, rarely greenish, frequently becoming conglomerate from pebbles "of gray limestone containing organic remains of the Trenton formation," besides thin-bedded gray limestones.

4. Red and green and chocolate-colored shales, often interstratified with thin bands of light gray sandstone, which is sometimes calcareous.

5. Coarse-grained, green, massive sandstones, holding scales of mica and graphite. "They appear to derive their prevailing color from chlorite, but red layers, as coarse as the green, and holding nearly as much chlorite, are in some parts interstrati-

fied." These rocks are often coarsely conglomerate, with quartz pebbles, "which sometimes appear to become mingled with pebbles and even boulders of gray limestone, holding fossils probably of the Trenton formation." Red and green slates are interstratified with this division.

§ 182. This succession, the description of which is abridged from that given in the Report of 1849, was determined almost wholly from the section seen near Quebec, on the island of Orleans and at Point Levis, although details of some of the divisions were gathered from other localities. The region farther eastward was, as already shown, too much disturbed to give any satisfactory evidence as to the sequence, while to the southwest the strata are concealed, for long intervals, by the great mass of superficial deposits, and but few outcrops, and these of small portions of the series, are met with. Thus, the fossiliferous limestones are known to the southwest of Point Levis within the limits of the province, only at and near Phillipsburg on Lake Champlain. The green sandstones of the series are not met with in this vicinity, but are seen a little to the northward, in Milton, Roxton and Granby, and at various points from the St. Francis river to the vicinity of Quebec, beyond which they are largely displayed in the region to the northeast.

§ 183. The presence of chlorite in these sandstones was noticed at several localities below Quebec in the interval between the crystalline rocks of the Notre Dame and the Shickshock Mountains, (Report of 1849, page 47) and also in Granby (Report of 1847, page 25). Here the green sandstones, with some red beds, are occasionally calcareous, and often conglomerate, holding pebbles both of quartz and of feldspar, together with scales of mica and of graphite, and constituting an arkose. The graphite, and the chlorite to which they owe their color, are more abundant in the finer than in the coarser beds. Interstratified with these sandstones, and with red and green slates, some of which also abound in scales of mica and of chlorite, are two calcareous layers, one and two feet in thickness, earthy in texture, and weathering brownish from the presence of manganese, but within of a green color, evidently due to a large admixture of chlorite, (as was shown by a partial analysis at the time,) and containing a small proportion of oxyd of chromium.

A careful study of this locality was subsequently made by the writer, and the results of a chemical analysis are given in the Report for 1853–56 (page 474). The green earthy mass held imbedded scales of chlorite, and yielded to dilute acids about 30.0 per cent of carbonate of lime, besides small portions of magnesia, manganese, iron and alumina. The residue contained no lime, but gave of silica, 53.20; alumina, 7.90; protoxyd of iron, 15.75; magnesia, 8.79; titanic acid, 6.30; oxyds of manganese, chromium, nickel, and loss, 2.60; alkalies, 0.66; volatile, 4.80=100.00. The oxyd of chromium was found equal to 0.30, and that of nickel to 0.15 per cent.

§ 184. The presence of these chemical elements, and of the disseminated chlorite, which evidently forms a considerable proportion of the matter analysed, were, at the time, considered as evidences of a commencement of metamorphism in the sedimentary strata, and as marking the passage of these into the crystalline rocks of the Notre Dame range, which, in accordance with the view then held by most American geologists (as set forth in the preceding chapter), were supposed to be no other than these same strata in a highly altered condition and, in the immediate vicinity of Granby, abound in chloritic schists, and in titaniferous iron ores, with manganese, chrome and nickel. The more simple and obvious view that these matters, like the quartz, feldspar, graphite and mica of the arkose, had come from the disintegration of the adjacent crystalline formation was then rejected by the writer, as being incompatible with the notion of the contemporaneous origin of the two series of crystalline and uncrystalline rocks, which was at that time unquestioned, except by Emmons. This geologist, as we have seen (§ 65, 107), had already noticed the existence of chlorite in these sandstones in Vermont and in New York, but maintained that it was derived from the "chloritic slate along the eastern border," and also suggested the presence in these sandstones of the "debris of hornblende."

§ 185. These sandstones, where they appear on the St. Francis river, are traversed by dykes of greenstone, and about two miles below, in Wendover, is a great development of greenstone, sometimes porphyritic, and at other times amygdaloidal, with agates and calcite. These masses are apparently conform-

able to the stratification, and are associated with graptolitic shales, into which the amygdaloid seems to graduate. Some of the beds are apparently a breccia, made up of fragments of the porphyritic greenstone, cemented by calcite (Geology of Canada, 1863, pages 243, 719). The greenstones are traversed by brecciated veins carrying sulphuretted ores of copper. Similar greenstones and amygdaloids are found farther northeast in the same strike, at St. Flavien, interstratified with red slates and calcareous conglomerates. Here also, sulphuretted copper ores are found both in the strata and in transverse veins, in addition to which native copper occurs with calcareous spar in druses in the conglomerate. "The whole band has a striking resemblance to some of the rocks of the Upper Copper-bearing series of Lake Superior." (Ibid, pages 242, 720.)

§ 186. In the extension of this belt to the southwest of the St. Francis large beds of magnesian limestone are found, associated with dark gray slates, and abounding in a fucoid resembling *Buthotrephis flexuosa* of Emmons. These are accompanied with great interbedded masses of greenstone, like those of Wendover and St. Flavien, while the limestones contain, in numerous localities, sulphuretted copper ores, as in Wickham, Durham, Upton and at Actonvale, where a mine was formerly wrought from which rich ores, yielding over 1,000 tons of copper, were extracted. These ores were chiefly found in a limestone-conglomerate, occasionally presenting the aspect of a breccia, the fissures of which were filled with variegated ore, calcite and quartz; and at other times forming a compact mass, in which rounded and angular fragments of limestone, and others of chert, were enclosed in a paste of vitreous and variegated sulphurets of copper, which are seen in polished sections to present a banded or stratified arrangement. The conditions at Upton, where copper-pyrites occurs, are very similar. (Geology of Canada, 1863, pages 241–244; 712–720.)

§ 187. The greenstones of Actonvale and Upton were examined chemically by the present writer, and found to consist of a basic feldspar, sometimes cleavable, with hornblende or pyroxene, and an amorphous green hydrated silicate related to chlorite. They were shown to resemble closely in composition

the greenstones described by Whitney from the Upper Copper-bearing rocks of Lake Superior. (Ibid, page 604.)

§ 188. This remarkable development of copper ores along a portion of the belt does not seem to be dependent upon the presence of the greenstones, since the ores appear in the limestones in Wickham and Durham, near Actonvale, where the greenstones are unknown. This, moreover, is the case at St. Henri and Point Levis, near Quebec, in both of which places the red slates of the series contain plates and masses of native copper, sometimes of several pounds weight. It is probably however to the presence of these hard greenstone rocks that are due many outcrops of the softer copper-bearing limestones, which elsewhere are worn down and concealed beneath the superficial deposits.

§ 189. We have now to inquire into the reasons which led the geological survey of Canada to assign the sedimentary rocks on the south side of the St. Lawrence to the upper part of the Champlain division of the New York series. These reasons may be considered under two heads. In the first place is to be mentioned the continuity and identity of this series with the Argillite and Graywacke series in western Vermont and eastern New York, which had been referred by Mather to the Hudson River group, (considered to be the stratigraphical equivalent of the Loraine shales) and the Oneida or Shawangunk formation. (§ 71, 72, 73.) To this was to be added the clearly expressed opinion of Emmons, in 1842, that the green sandstones examined by him at Quebec were to be assigned to the last named formation. (§ 65, 112.)

§ 190. In the second place were to be considered the facts observed in the vicinity of Quebec, where a nearly complete section of the series is to be seen in close proximity to the Trenton limestone. In a geological account of this region by Dr. J. J. Bigsby, published as early as 1827, (Proc. Geol. Soc. I, 37,) he described the fossiliferous limestone resting in a nearly horizontal attitude upon the ancient gneiss on the northwest side of the St. Lawrence, at Beauport, while the heights on both sides, including the city of Quebec, Point Levis, and the island of Orleans, were said to consist of "a slaty series of shales and graywacke," occasionally passing into a brown lime

stone, and alternating with a calcareous conglomerate in beds, some of them charged with fossils, which, according to him, were derived from the horizontal limestone of Beauport. From this he concluded that the Graywacke series, which is highly inclined, is more recent than the limestones. These he supposed might belong to the carboniferous period, to which also he referred the Graywacke series. This contains small veins of a bituminous matter, regarded by him as coal, and what he supposed to be vegetable impressions, called by him fucoids, under which name two species from this locality were described by Ad. Brongniart in 1828, as pointed out by Prof. James Hall, who, nearly thirty years later, described and figured these impressions as new forms of graptolites. Geol. Sur. of Canada, Decade II, page 60, and Report for 1857, page 111.)

§ 191. Bigsby's view of the greater antiquity of the Beauport limestones was, as we have seen, adopted as probable by Logan, (§ 128) and was confirmed by Admiral Bayfield, who in 1845 (Geol. Journal, I, 455) expressed the opinion that the flat limestones of Beauport and of Montmorenci pass beneath the Graywacke series. He, however, was aware that these limestones, which had been traced, at intervals, along the north side of the St. Lawrence to Montreal, belong to the Trenton formation of the Champlain division, and hence referred the Graywacke series, which was still supposed to hold in its conglomerates fossils derived from this limestone, to the higher members of that division. The presence in the shales of the Graywacke series in Gaspé, of graptolites, which were supposed to belong to the Utica slates, served to confirm the conclusion that the position of this series had been correctly determined. The graptolites of Point Levis were not re-discovered until 1854, but this locality had, as early as 1848, yielded to Logan two brachiopodous shells, mentioned by him as "*a Leptaena* very like *L. sericea*, and an *Orthis* very like *O. testudinaria*, and taken by me to be these species," which are characteristic of the upper part of the Champlain division. (Amer. Jour. Science, [2] XXXIII, 106.)

§ 192. It is to be noticed that a few miles to the northeast of Quebec, rocks undoubtedly of the age of the Utica and Loraine formations overlie conformably the Trenton limestone,

as is seen on the Montmorenci river, and beyond, along the left bank of the St. Lawrence; and also that a few miles to the southwest of Quebec, strata of these same two formations, occupying similar stratigraphical relations, appear on both sides of the St. Lawrence, and are thence traced continuously to the valley of Lake Champlain. These, moreover, offer such lithological resemblances to the Graywacke series of Quebec and Point Levis, (which, as has been shown, extends for hundreds of miles to the northeastward, along the right bank of the St. Lawrence,) that the two series of rocks were readily confounded, and thus the whole of the belt of sedimentary strata along the southeast side of the St. Lawrence, from the valley of Lake Champlain to Gaspé, came to be regarded as younger than the limestones of the Trenton group. (Hunt, Chem. and Geol. Essays, page 395.)

§ 193. The Trenton limestone, along the left bank of the St. Lawrence near Quebec, is in many places almost horizontal, but is affected by occasional anticlinals running north-east and south-west, having the steeper dips on the south-east side. These, in some cases, pass into considerable faults or dislocations, with downthrows to the southeast. One of them is traced along the southeast side of the road from Beauport church to the River Montmorenci, where the displacement gives rise to the well-known water-fall of about 250 feet. The Trenton limestone, lying nearly flat at the top, is seen at the foot of the cascade, resting, with its edges upturned, at an angle of 57° against the gneiss, and dipping to the southeast beneath a conformable succession of beds of the Utica and Loraine shales, which extend to the shore of the St. Lawrence. Other and similar dislocations, nearly parallel with this, occur on the northeast bank of the St. Lawrence above and below Quebec, examples of which are seen at Pointe aux Trembles and at Ste. Anne de Beaupré, in which the Utica, in the one case, and the Loraine in the other, are found leaning, with a high southeast dip, against the gneiss. (Report for 1852, pages 28–40).

§ 194. At a distance of about eight thousand feet across the line of strike from the Beauport and Montmorenci dislocation, against which the Trenton, Utica and Loraine strata are made to dip southeast at a high angle, we find rising from the low

lands behind the city, and from the waters of the St. Lawrence, the Graywacke series which forms the heights of Quebec, Sillery, Cape Rouge, and Point Levis, and the island of Orleans. These strata, near Cape Rouge, dip S. 25° E., and on the island of Orleans, S. E., in both cases at an angle of about 50°, and though affected by many minor undulations, have a prevailing high inclination to the south-east. The thickness of the series here displayed, as measured by Logan, was estimated at over 5,000 feet, and the sequence is essentially that previously described, (§ 181).

§ 195. In 1855 was published the Esquisse Geologique, already noticed, (§ 144,) in which (page 36) the rocks of the southeast side of the St. Lawrence were described as forming part of a great paleozoic area, including also the New England states, together with Ontario, New York, and the whole of the paleozoic rocks to the south and west. This vast region was, according to Logan, divided into two parts by an anticlinal axis, which, following the Hudson river and passing to the east of Lake Champlain and the Richelieu river, reaches the St. Lawrence at Deschambault, about twenty-five miles above Quebec. The region to the west of this, designated by him the western basin, includes the comparatively undisturbed strata of Ontario and New York, and the Appalachian and Michigan coal-fields; while to the east of this axis are found the disturbed and, in part, crystalline rocks already described, which surround the coal-fields of New Brunswick and Rhode Island. This attempted generalization, it will be seen, was but a repetition of that already made by Mather, who, in 1843 had already traced this supposed axis from New Jersey nearly to Lake Champlain, and had asserted that the rocks on the east side of it are nothing more than the disturbed and modified equivalents of those on the west (§ 69, 72, 81).

§ 196. This anticlinal, in its course through eastern Canada, was declared to bring to the surface the Trenton limestone and "the lower part of the Hudson river or Loraine shales," resting upon which were the rocks of Quebec, Orleans and Point Levis—now first designated the Quebec formation—overlaid by the red and green shales and the green sandstones of division 5, (§ 181) which, from their occurrence at Sil

lery, were designated the Sillery formation, and declared to correspond to the Oneida or Shawangunk of New York. In the geological map published with the Esquisse, these Quebec and Sillery formations were represented, respectively, as the equivalents of the Hudson River group and the Oneida formation, and in accordance with the views of Mather, the crystalline rocks of the Notre Dame Moutains were regarded as the altered equivalents of these (Esquisse, pages 40–60).

§ 197. The graptolites of Point Levis were first described by Prof. James Hall in 1855 (Report for 1857, page 109). They were unlike those hitherto known in the Utica slates of the Champlain division, and were regarded as belonging to a higher horizon—according to Prof. James Hall, "that part of the Hudson River group, which is sometimes designated as Eaton's Sparry limestone (§ 52),—being near the summit of the group." (Ibid, page 117).

§ 198. These rocks had been carefully traced by Logan from Canada into Vermont, and found to include the Red sandrock of that region, which Adams, in 1846, and W. B. Rogers, in 1851, had already, in opposition to the views of Emmons, assigned to the summit of the Champlain division (§ 116, 117, 118). The slates associated with the Red sandrock at Georgia in Vermont subsequently yielded two species of trilobites, which were described by Prof. James Hall, in 1859, in the 12th Reports of the Regents of the University of New York, as belonging to the genus *Olenus*. These remains, subsequently referred by him to a new genus, named *Olenellus*, were in 1860 described by Emmons as species of *Paradoxides*. That these trilobites had the characters belonging to a much lower horizon than that assigned to them by Adams, Rogers, and Logan, was well known to Prof. Hall, who, however, described them as occurring in the Hudson River group, and in justification thereof declared in a note, "I have the testimony of Sir William Logan that the shales of this locality are in the upper part of the Hudson River group, or form part of a series of strata which he is inclined to rank as a distinct group, above the Hudson River proper." (Amer. Jour. Science, [2] XXXI, pp. 213, 221). For a farther history of the question, see the author's Chemical and Geological Essays, pp. 391–402).

§ 199. In 1856 the present writer found, not far from the graptolitic shales of Point Levis, beds of a bluish-gray limestone abounding in organic remains. These were imperfectly preserved, but among them was a pygidium recognized as belonging to an unknown trilobite, which was placed for examination in the hands of the late Mr. E. Billings, (then recently attached as paleontologist to the geological survey of Canada). This was the species subsequently described by him as *Bathyurus Saffordi*. Farther explorations in 1857, and succeeding years, brought to light a large number of species of organic remains in these and other limestone-beds at Point Levis, which were studied and described by Mr. Billings.

§ 200. A similar fauna, though less abundant, was found in the limestones of Phillipsburg and the adjacent towns of Stanbridge and Bedford, near Lake Champlain, and also on the island of Newfoundland. Without counting the graptolitic fauna, there have been got from the limestones of these various localities 168 species of organic remains, of which seventy-four are crustaceans. More than one-half of these forms are met with in the limestones of Point Levis. Of this considerable fauna, according to Billings, five species are known in the Chazy limestone, and twelve in the Calciferous sandrock of the Ottawa basin, besides several which are found on the Upper Mississippi, in strata referred by Owen to the Potsdam sandstone, but not a single species belonging to the higher members of the Champlain division; while the affinities of the new and hitherto undescribed species, are with the lower rather than with the higher formations of the division. From all these facts, Billings drew the conclusion that the horizon previously assigned to these fossiliferous strata by the Canadian survey was not the true one, and that their real position was at the base and not at the summit of the Champlain division. From this it followed that the Graywacke series of Quebec and Point Levis was older and not younger than the Trenton limestone.

§ 201. These conclusions were announced to Sir William Logan in a letter to Mr. Barrande, dated in December, 1860, and published in March, 1861, (Amer. Jour. Science, [2] XXXI, 216), when he expressed the opinion that the Graywacke series

of Quebec was "a great development of strata about the horizon of the Chazy and the Calciferous, brought to the surface by an overturn anticlinal fold, with a crack and a great dislocation running along the summit," by which the rocks in question (henceforth called the Quebec group,) "were brought to overlap the Hudson River formation." He, at the same time, declared that "from the physical structure alone, no person would suspect the break that must exist in the neighborhood of Quebec and, without the evidence of fossils, every one would be authorized to deny it." Logan was thus led by the paleontological evidence furnished by Billings to adopt the conclusion as to the age of these rocks which had been maintained by Emmons since 1846, when the latter declared that the series which he had previously referred to the Hudson River group, in eastern New York and Vermont, was a modification of the Calciferous sandrock, protean in character, and including a great mass of sandstones, shales and limestones (§ 95, 96, 98). This priority on the part of Emmons was thus stated by Logan in the letter above cited, "Prof. Emmons has long maintained, on evidence which has been much disputed, that rocks in Vermont which, in June last, I, for the first time saw, and recognized as equivalent to the magnesian part of the Quebec group, are older than the Birdseye formation (the basal beds of the Trenton). The fossils which have this year been obtained at Quebec pretty clearly demonstrate that in this he is right."

§ 202. These were the rocks which Emmons described, in 1846, as superior to the Granular quartz-rock, the Stockbridge limestone, and the Magnesian slate (which constitute the lower portion of his Taconic system,) and included under the general name of the Taconic slates (§ 103). It was these which, in 1855, he separated from the lower members and distinguished by the name of Upper Taconic. This latter division he declared to contain, in its upper portions, the remains of graptolites, fucoids and crustaceans (§ 104, 107). Although at an earlier date Emmons had spoken of his Taconic system as inferior to the whole of the Champlain division, this view was subsequently confined to the Lower Taconic, since the Upper

Taconic, as defined in his *American Geology*, included not only "the modified and protean Calciferous sand-rock," but the Potsdam itself (§ 114). It is apparently by one of those inconsequences already noticed (§ 113) that in the same work, in his account of the Granville section (§ 108) he makes the Taconic slates to underlie the Calciferous sandrock. To Emmons undoubtedly belongs the credit of having first discovered the true horizon of these Upper Taconic rocks, which was subsequently established, independently, by the paleontological studies of Billings.

§ 203. Logan, however, as we have seen, did not adopt for these rocks the name of Upper Taconic, which had been previously given them by Emmons. Referring to the description of the Graywacke series given in § 181, it will be remembered that, in 1855, the rocks there included in division 5 had been called the Sillery, while divisions 1–4 had been designated the Quebec formation. For the latter, the name of Levis was now substituted, and these, together with the Sillery, were called, in Logan's letter to Barrande, the Quebec group; of which a section, with measurements, as displayed in the island of Orleans, was first given in the Geology of Canada (1863), page 227. In the Report of 1863–66 (page 41), for greater convenience in tracing out the supposed parallelism between these strata and the crystalline rocks of the Notre Dame range, there was established a third division in the Quebec group, by giving to its middle portions the name of the Lauzon formation, taken from the seigniory of that name, in which Point Levis is situated.

§ 204. The Levis formation, as thus limited, included divisions 1–9 of the Orleans section (above referred to) comprising 1,285 feet of green and gray shales, often dolomitic, together with some sandstones, limestones and conglomerate layers. About midway in this formation is a belt of gray argillaceous shales holding *Phyllograptus typus;* while other organic forms, obscure and undetermined, occur in calcareous beds, both above and below this belt.

The Lauzon formation, including the divisions 10–17 of the Orleans section, measures 3,740 feet, and consists, like the previous one, of sandstones, conglomerates and shales, in which

red and purple colors often prevail, especially towards the summit, where is a mass of 1,000 feet or more of red shales, well seen at Cape Rouge, in which occur a species of *Lingula* and *Obolella pretiosa*. Near the base of the Lauzon are several hundred feet of soft shaly sandstones, containing in parts, abundant green grains of glauconite, analyses of which will be found in the Geology of Canada, page 486.

§ 205. To the Lauzon succeeds the Sillery formation, not seen in the Orleans section, consisting of greenish, drab-weathering sandstones, colored by chloritic matter, and holding scales of mica and of graphite, together with small fragments of green and black slates, often calcareous, and becoming, in some layers, a quartzose conglomerate. These sandstones, like the beds of the two formations just described on Orleans Island, dip to the southeast at an angle of about 50°. Mr. Billings united with the Sillery the mass of red shales assigned by Logan to the summit of the Lauzon, which contain in two localities the *Obolella* named, and are interstratified with the green sandstones, from which they cannot be separated. (Paleozoic Fossils, Vol. I, pages 62, 69.) The thickness of these sandstones was by Logan estimated at 2,000 feet, making the total volume of the Quebec group, as defined by him, a little over 7,000 feet.

The lithological and chemical characters of these green chloritic sandstones of the Sillery formation have already been described. (§ 183, 184.)

§ 206. It is not easy to identify the different sub-divisions of the Orleans section, either in the city of Quebec or at Point Levis. Much interest attaches to the latter locality, because it is there that have been obtained the organic remains which have been relied upon to fix the geological horizon of the Quebec group. It will be well, in the first place, to consider some of the lithological peculiarities of the strata here met with, as described by the present writer in 1856.

The rocks at Point Levis present interstratifications of pure limestones, dolomites, sandstones and argillaceous shales. "Both limestones and dolomites are very irregular and interrupted in their distribution, the beds sometimes attaining a considerable volume, while at other times they thin out, or are replaced by sandstones. The limestones frequently form masses of

many feet in thickness, which are without visible marks of stratification, and destitute of organic remains. These masses are compact, conchoidal in fracture, sub-translucent, and exhibit a banded agatized structure, which leads to the conclusion that they are chemical deposits from water—in fact, veritable travertines. Their colors are pearly grey of different shades, and occasionally pale green ; they weather smooth and white. Analysis shows that they are pure carbonate of lime, and contain neither silica, iron, nor magnesia, in appreciable quantities. Interstratified with these travertines, however, there are beds of fine granular opaque limestones, weathering bluish-grey, and holding, in abundance, remains of othoceratites, trilobites, and other fossils, which are replaced by a yellow-weathering dolomite." These have been already noticed in § 199.

§ 207. "The dolomites occur both among the travertines and the fossiliferous limestones, sometimes in small lenticular masses, or in layers of a few lines, interposed in masses of limestone. At other times the layers of dolomite are several feet in thickness." Unlike the associated limestone, the dolomites contain an admixture of sand and clay, and from five to ten per cent. of carbonate of iron, which causes them to weather reddish-brown. They are slightly bituminous, and include grains of pyrites and veins of calcite, but were never found to contain fossils, and often pass into a dolomitic sandstone, with rhombohedral cleavages, due to the crystalline matrix. In one example, a compact ferriferous dolomite contained half its weight of clayey matter. It is chiefly these magnesian beds which become conglomerate. "In addition to sand and clay, the dolomites frequently enclose grains and rounded fragments of limestone and of dolomite, both seemingly derived from adjacent strata, so that we have beds consisting of pebbles of limestone, often having the characters of the travertine, of dolomite, and occasionally of quartz and of argillite, the whole cemented by a ferriferous dolomite. At other times the cement of the conglomerate is a nearly pure carbonate of lime." (Report for 1853–56, pages 464–466). These im-

bedded fragments of argillite are purplish or greenish in color, lustrous, and sometimes apparently chloritic.

§ 208. Some of the finely granular gray limestones above described, which contain small patches and layers of yellowish dolomite, and moreover hold organic remains replaced by the same material, have, although in nowise conglomerate in their origin, an aspect which suggests the conglomerates already noticed, and have often been mistaken for them. Such is the nature of some, at least, of the calcareous bands which have yielded the organic remains at Point Levis. *Bathyurus Saffordi*, a typical species, was first found in a bed of compact limestone, not conglomerate, and Logan satisfied himself, as he tells us, that the fossils collected by him are of the age of the strata. Certain of the forms there obtained, he afterwards thought, might be included in masses derived from older strata, but he declared, in accordance with the views above expressed, that "some of the fossiliferous portions of the Point Levis bands, having the same color and texture as the supposed boulders, possess the character of original sediments, or of concretionary masses, and it is difficult to separate the fossils of these from those of the rolled masses." (Geology of Canada, page 860.)

§ 209. The strata of Point Levis contain two unlike faunas, which are found in unlike rocks, and in localities entirely distinct from one another. We have, in the first place, a series, chiefly of argillaceous shales, abounding in graptolites; and in the second, a series of bands and lenticular masses of limestone, sometimes apparently conglomerate, which hold a remarkable trilobitic fauna, and are interstratified with sandstones, and with shales which are distinct from those mentioned above, and have yielded no graptolites. Both of these were, however, by Logan, included in the Levis division of the Quebec group. The distinction between these two fossiliferous formations is not made clear in the Geology of Canada (page 861), where these rocks are briefly described. The plan of Point Levis, there referred to, however, which is published in the *Atlas*, and is on a scale of three inches to a mile, shows the course

of every band of limestone, the outcrops, and the various localities from which fossils have been collected. With this, and its accompanying section, aided by the description given in the letter of Logan, (§ 201,) the following statement of the relations of these rocks will be intelligible: The strata at Point Levis, with a high south-east dip, rise rapidly from the shore of the St. Lawrence, which is parallel to their strike, and form a succession of bold ridges, attaining a height of 400 feet or more, across which, by a series of undulations, the limestones, conglomerates, and shales of the Quebec group are distributed over a breadth of more than two miles transverse to the strike. In this distance they exhibit two well-marked anticlinals, with indications of a third. The intermediate synclinals are sharp and, according to Logan, are overturned, so that the strata on both sides dip steeply to the south-east.

§ 210. Near the lower ferry at Point Levis is a cliff about 100 feet high, composed of shales, with thin-bedded limestone and some conglomerate layers, the whole dipping to the south-east at a high angle. The strata, which are dark gray, and very tender, abound in graptolites and related forms. Prof. James Hall has described from this locality not less than forty-two species, which are thus divided among the following genera: *Graptolithus, 25; Retiolites, 1; Reteograptus, 2; Phyllograptus, 5; Dendrograptus, 3; Thamnograptus, 3; Dictyonema, 3.* With these were found species of brachiopods described by Billings under the names of *Lingula Irene, L. Quebecensis*, and *Obolella desiderata*, besides an *Orthis* and a *Strophomena*, both undescribed, and in the accompanying limestone an unnamed *Tetradium*, a minute trilobite, which was described under the name of *Shumardia granulosa*,* and another undescribed, which was referred to *Dikellocephalus.*

§ 211. Leaving this belt of fossiliferous strata, we ascend the coast ridge, and reach what is described on the plan as the middle ridge. Here, at a point of about five eighths of

*This, by a typographical error in the Geology of Canada, (page 864) is placed in column I, instead of A, where it belongs. See Billings, Paleozoic Fossils, page 93.

a mile east of the graptolitic shales, and three eighths of a mile across the strike from the line of these, we find the first of the limestone beds with the trilobitic fauna, which is confined to certain limestone bands marked on the plan, (and in the Geology of Canada,) 2-8, numbering to the south-east; the whole occupying a breadth of less than a quarter of a mile across the strike.

Not one of the fifty species found in the graptolitic zone to the north-west has been here met with, and, with the exception of an undescribed *Dictyonema*, not a single species belonging to the order of the Graptolitideæ. The species from these limestones catalogued by Mr. Billings, are 103 in number, of which 69 have been described. Passing over the long list of brachiopods, gasteropods, cephalopods, etc., we find not less than 31 described species of trilobites, divided as follows among the genera named: *Agnostus, 3; Amphion, 1; Arionellus, 2; Asaphus, 2; Bathyurus, 8; Cheirurus; Conocephalites* (*Conocorphye,*) *1; Dikellocephalus, 7; Endymion, 1; Holometopus, 1; Menocephalus, 3;* besides one each of *Nileus, Ampyx,* and *Illænus,* undescribed. Of these, the last two named are found, with *Holometopus*, only in band 8, while one species of *Bathyurus* occurs in band 2; all the others being confined to the bands 3 and 4, and often common to the two. These contiguous bands were, by Logan, regarded as the same one, repeated by a dislocation or, as he afterwards supposed, by an overturned synclinal fold.

§ 212. A few of the organic remains found at Point Levis have been observed on the island of Orleans, but it was conceived by Logan that both the graptolitic and the trilobitic zone were included in the first ten divisions (measuring about 2,000 feet) of the Orleans section, in which he did not attempt to fix the relative positions of the two fossiliferous horizons. He however noticed (Geol. Canada, page 230) that the argillites between the limestone bands at Point Levis often include red layers, in which respect they differ from the lower portion of the Orleans section, designated the Levis formation; while, on the contrary, the upper part of that section, referred to the Lauzon, has red

argillite bands at several horizons; thus making it probable that a large portion of the Levis section belongs to the so-called Lauzon. It will be remembered, however, that a thick band of argillaceous shales, holding *Phyllograptus*, and the supposed equivalent of the graptolitic zone at Point Levis, is found in the Orleans section, about 700 feet from its base.

§ 213. Billings published his first account of the fauna of these limestones in the *Canadian Naturalist*, in August, 1860, and Barrande, commenting thereon, in 1861, (Bull. Soc. Geol. de France, 2me série, tom. XVIII, page 203,) called attention to the fact, that while the limestones of band 3 (No. 1 of Billings) had, at that time, yielded trilobites of the genera, *Arionellus*, *Dikellocephalus*, *Menocephalus*, and *Conocoryphe*, the band 4 (No. 2 of Billings) contained none of these, but only *Bathyurus* and *Agnostus*, with *Cheirurus*. This latter genus, together with associated brachiopods and species of *Orthoceras* and *Cyrtoceras*, lead him to refer the band 4 to his second fauna; while the band 3, according to Barrande, belonged clearly to the first or primordial fauna. Subsequently, however, Billings found *Orthoceras* in 3, while two species of *Dikellocephalus* were declared to be common to 3 and 4, and he was led to believe, with Logan, that the two bands, if not identical, belong to the same horizon, and present an admixture of forms belonging to the two faunas.

§ 214. At a later date, in 1863, Billings expressed the opinion that the forms at first described by him as species of *Arionellus*, should be referred to the new genus *Ptychaspis* of Hall, from the western Potsdam, which would also include one of the Levis species previously called a *Dikellocephalus*. A new genus, *Loganellus*, proposed by Devine for a trilobite from Point Levis, at first referred to *Olenus*, will include, according to Billings, other species of the so-called *Dikellocephalus*, as well as some of the western forms referred by Shumard and by Hall to *Conocephalites*. Billings now expressed the opinion that the Levis belonged to a somewhat later period than that of the large species of *Paradoxides*, and declared that we have, in the Levis lime-

stone, "the leading generic types of the dominant family of the Potsdam trilobites." (Pal. Fossils, pages 198-200.) This was in accordance with the declaration by Professor Hall, in 1861, that, judging from its trilobitic fauna, the Levis limestone "is in parallelism with the Potsdam and Calciferous strata." (*American Journal Science*, [2,] xxxi., 222.]

§ 215. The rocks now included in the Quebec or Hudson River group by Logan, were, however, found to contain still another fauna, which included the two species of *Olenellus* described by Hall from Georgia, Vermont, (§ 198.) The Red sandrock of that vicinity has also yielded two species of *Conocoryphe* and an *Obolella*, besides, according to Perry, crinoidal stems. Subsequently, these same species of *Olenellus*, together with the *Conocoryphe*, were discovered in a limestone at Forteau Bay, on the north side of the strait of Bellisle, with three species of *Bathyurus*, *Salterella*, and *Archeocyathus*, besides numerous brachiopods, including the *Obolella* found in the Red sandrock of Vermont. These limestones, associated with red and green shales, have an observed thickness of 143 feet, and overlie conformably a mass of nearly horizontal red and grey sandstones, often conglomerate, which rest upon Laurentian gneiss, and are made up of its ruins. Many beds of these sandstones, which have an aggregate thickness of 231 feet, are penetrated vertically by *Scolithus linearis*.

§ 216. On the opposite side of the strait of Bellisle, which is here from ten to fifteen miles in width, appears a belt of paleozoic rocks, stretching thence along the north-west side of the island of Newfoundland for a distance of 180 miles to the south-west. It is limited to the south-east by a parallel range of crystalline rocks, in part Laurentian.

Along the shore, this belt of sedimentary strata lies nearly horizontal, but where we can examine the strata to the south-east, across the strike, as at Pistolet Bay, which is at the north-east extremity of the island, and at Bonne Bay, 180 miles to the south-west, they are found to be greatly disturbed, faulted, and often inverted as we approach the crystalline range. This region was examined by Mr. James Richardson, in 1861 and 1862, and from his notes and col-

lections the officers of the Canada Survey prepared the descriptions given in the Geology of Canada, (pages 287–293, and 864–880.)

§ 217. The arrangement of these rocks on the two sides of the strait of Bellisle is supposed to be that of a shallow synclinal. A series of beds on the island, chiefly of sandstones and magnesian limestones, believed to follow the beds already noticed on the mainland, and making, with these, a total thickness estimated at 1,147 feet, was described under the name of the Potsdam group. Succeeding these are not less than 3,200 feet of limestones which, from their organic remains, were referred to the Calciferous formation. To this succeed 1,400 feet of limestones, often conglomerate, with black shales, supposed to belong to the Levis formation, which, at that time, included the Lauzon division. (§ 203.) These rocks, along the north-eastern part of the belt, present very slight inclinations to the south-east, but farther to the south-west, where the crystalline range is nearer the shore, they are affected by undulations running north-east and south-west, and are highly inclined to the south-east, and sometimes even vertical in altitude.

§ 218. At the south-western extremity of the belt examined, where Bonne Bay affords a transverse section, there is found a series of blackish-blue argillites, with transverse slaty cleavage, interstratified with, and underlaid by gray quartzites. This group, with a thickness of 600 feet, and without observed fossils, is followed by a series of limestones with shales and sandstones, estimated at 1,400 feet, holding organic remains like those of the Labrador coast, and hence referred to the Potsdam group. Other fossiliferous strata of the series occur in the neighborhood, but "they are much contorted, and it is difficult to make out the true succession." Overlying these, in conformable sequence, appear 2,000 feet of greenish sandstones and shales, referred to the Sillery formation, the whole dipping south-east at angles of from 45° to 80°; while further to the south-east, across an arm of the bay, rises a mountain of serpentine, with talcose slates, more than 2,000 feet in height.

§ 219. At Cape Norman, at the north-east extremity of Newfoundland, most of these fossiliferous strata appear, at first with moderate dips to the south-east, but, in that direction, soon become affected by great undulations, and are often vertical or even overturned along the west shore of Pistolet Bay, where the fossiliferous limestones and slates are seen, devoid of any crystalline character. On the east side of the same bay, is a mass of hornblendic, feldspathic, and chloritic rocks, interstratified with serpentine and diallage-rock, the whole estimated at about 1,200 feet in thickness. Succeeding these, on the south-east side, is a great development of chloritic sandstones and conglomerates, which occupy a breadth of several miles, and are supposed to represent the Sillery formation; which here occurs, not between the fossiliferous sediments and the serpentines, as at Bonne Bay, but separated from the former by a mass of similar serpentines. The rocks in Pistolet Bay are affected by four dislocations, one of which is supposed to be a downthrow of about 1,400 feet to the south-east side, "while the other three are up-throws to the south-east." Several other similar dislocations, running with the strike, or nearly so, are observed further south-west, towards Bonne Bay, "all of them being up-throws on the south-east side." (Geol. Canada, page 876.)

§ 220. After a further and careful study of the collection of fossils from these Newfoundland rocks, Billings declared that the characteristic fauna of the Levis limestones (found also at Phillipsburg and Bedford, near Lake Champlain) had been met with in Newfoundland, only at Cow-Head, a point not far from the south-west extremity of the belt of fossiliferous strata. He also recognized a series of beds holding the organic remains of the typical Calciferous sandrock of the Champlain division. These strata, however, if we may trust the observations, do not immediately underlie the Levis limestones, but are separated from them by more than 2,000 feet of limestones containing a fauna distinct alike from the Calciferous and the Levis. While including some species belonging to the Chazy, and others very similar to, if not identical with those of the Black River and

Trenton limestones, most of the typical species of these formations of the Champlain division are wanting. These intermediate strata were subsequently distinguished by the name of Upper Calciferous. "It would thus appear," in the language of Mr. Billings, "that the Levis limestones are at least 2,000 feet above the true Calciferous sand-rock. That so many trilobites, belonging to the dominant type of the Potsdam period, should occur in such a horizon, appears to be a most extraordinary fact. Judging from the fossils alone, I should say that the Levis immediately succeeds the Calciferous, but the physical evidence seems to show that this is not the case." (Paleozoic Fossils, vol. I, pages 66–207, and 371–377.)

§ 221. Beneath the strata regarded as the representative of the true Calciferous sandrock, which consist of limestones and geodiferous dolomites, are found beds holding *Lingula acuminata*, overlying a series of white sandstones and conglomerates, which contain, besides quartz pebbles, numerous worn fragments of blackish argillite. These beds were regarded as equivalent to the typical Potsdam sandstone of central Canada and northern New York, and were designated by Billings as the Upper Potsdam, while the name of Lower Potsdam was given to the basal beds on the Labrador coast, and those near Bonne Bay, containing *Olenellus*, *Conocoryphe*, *Obolus*, *Salterella*, *Archeocyathus*, etc. To this was also referred the Red sandrock of Vermont and its associated slates, and, subsequently, the strata holding a similar fauna from Troy, New York, which, according to Ford, rest, like the Red sandrock (§ 116,) in apparent conformity upon the upper members of the Champlain division, the whole succession dipping to the eastward. (American Journal Science [3] VI, 134.)

§ 222. The nomenclature thus adopted for these rocks was, in ascending order: 1°, Lower Potsdam; 2°, Upper Potsdam; 3°, Lower Calciferous; 4°, Upper Calciferous; 5°, Levis; 6°, Lauzon; 7°, Sillery. The formations, 2 and 3, in this series were regarded as the equivalents of the typical Potsdam sandstone and the Calciferous sandrock of the Champlain division, (Report, 1866–69, page 236). At the

same time the strata from St. John, in New Brunswick, and from St. John's, in south-eastern Newfoundland, which contain, besides *Conocoryphe* and *Agnostus*, species of *Paradoxides* and *Microdiscus*, were referred to a still lower horizon, under the name of the St. John's group, which is undoubtedly equivalent to some part of the Lower Cambrian of Wales. To this horizon also belong the *Paradoxides* beds of Braintree, in Massachusetts. (Hunt, Chem. and Geol. Essays, pages 405–407.)

§ 223. In 1868, an examination made by Mr. Richardson, of the south side of the St. Lawrence, from near Quebec, for a distance of more than 150 miles, as far as Bic, showed that a considerable part of the strata along the shore, at first called Hudson River group, and subsequently referred to the Lauzon division of the Quebec group, contains organic remains of Lower Potsdam age. These strata, consisting of quartzites and sandstones, with bedded limestones and shales, have a thickness of about 2,000 feet. The sandstones and quartzites are often conglomerate, containing pebbles and large masses of limestone, in which occur in abundance the fossils of the Lower Potsdam, but *Salterella* was said to be also found in the bedded limestones, and *Archeocyathus* in the shales. The chief localities of these fossils were at St. Denis and Bic Harbor. These strata were supposed to be unconformably overlaid by the Quebec group; but in a region, the stratification of which, as we have already seen, (§ 177) is so greatly disturbed, faulted, and even inverted, much more study is required before the true structure of the region, and the real age of these conglomerate beds can be satisfactorily determined. (Report for 1868, pages 120–130.)

§ 224. Without counting the Lower and the Upper Calciferous of Newfoundland, we have seen that the great continental belt of rocks, originally designated the Hudson River group, and subsequently called Upper Taconic and Quebec group, has already afforded us at least three distinct faunas: 1°, that of the Red sandrock, or so-called Lower Potsdam; 2°, that of the Levis limestone; and 3°, that of the Phyllograptus shales of Quebec, which have

also been met with in more than one locality in Newfoundland. Still another fauna, included in the Quebec group, will be described in § 233. In the language of Billings, "the Quebec group, in fact, consists of several formations, differing from each other lithologically and paleontologically, and yet forming a connected series." (Paleozoic Fossils, Vol. I, page 62.)

§ 225. A grave question here arises, as to the relation to the other members of the Quebec group, of the Sillery formation. This, when those were supposed to belong to the summit of the Champlain division, was referred to the overlying Oneida formation, and when they were, on paleontological grounds, assigned a position near the base of that division, was provisionally regarded as a superior member of the Quebec group. In an early chapter of the *Geology of Canada*, Logan, while inclining to this view, declared that "in describing the Quebec group the series will be considered as an ascending one, not so much, however, for the purpose of asserting the order of the strata, as to render more intelligible the facts connected with their geographical distribution." (Page 229). Billings, about the same time, noticing the *Obolella*, which was found in shales "interstratified with the Sillery sandstones, which are at present classified as the upper part of the Quebec group," adds, "but the question as to whether such is their true position or not, is considered an open one." (Pal. Fossils I, page 69). The Sillery sandstones, as seen at Granby (§ 178,) were plainly overturned, in an inverted synclinal or anticlinal; and their attitude in the vicinity of Quebec, and elsewhere along the south shore, where inversion seems to be the rule rather than the exception, (§ 177) was such that, as we have seen above, their real position in the series was by Logan regarded as undetermined.

§ 226. If not at the summit, their position must be at the base of the great series of strata in question. They were, however, very unlike the basal sandstones seen on the north side of the strait of Bellisle, and were met with in Newfoundland only in two localities in the north-west portion of the island, at Bonne Bay, and at Pistolet Bay. It will be

recollected that the crystalline rocks of the Notre Dame range had been by Logan asserted, in accordance with the hypothesis of Mather, to be formed by a metamorphosis of the strata of the Quebec group, and a horizon of serpentinic, hornblendic, and chloritic rocks, was supposed by him to occur at the summit of the Lauzon formation. At Bonne Bay, as described, the uncrystalline fossiliferous limestones and shales were seen to dip south-east, at a high angle, apparently beneath a conformable mass of the Sillery sandstones; while a little distance across the strike crystalline rocks, like those of Notre Dame range, rise in a mountain-mass.

§ 227. At Pistolet Bay the fossiliferous strata are also seen dipping to the south-east at a high angle towards a belt of similar crystalline rocks on the opposite side of the bay. Here, the Sillery sandstone is not seen in the interval, but appears on the south-east side of the belt of serpentinic, chloritic, and hornblendic rocks. Upon this relation of things, Logan remarks that the crystalline rocks here occupy their supposed position, towards the summit of the Quebec group, while the massive greenish chloritic sandstones succeeding them "would thus appear to occupy the horizon which has been provisionally assigned to those of the Sillery formation, near Quebec," adding that "further research, however, is yet required to establish the true relation of this formation to the Quebec group." (Geol. Canada, page 880.)

§ 228. The present writer has, for many years, believed that the position of the Sillery sandstones is at the base, instead of at the summit of the Quebec group, and that the whole series is more recent than the crystalline rocks of the Atlantic belt, to which the Notre Dame and Shickshock Mountains, and the similar crystalline rocks in Newfoundland (§ 218) belong. The order at Quebec, according to this view, is a reversed one, due to an inverted fold, while the dipping of the uncrystalline strata southwards towards the crystalline rocks, and apparently beneath them at Bonne Bay and Pistolet Bay, is connected with the numerous faults which, with up-throws on the south-east side, have been no-

ticed at the latter locality (§ 219.) These phenomena, alike at Quebec and in Newfoundland, are in close accordance with those seen everywhere along the north-western base of the Atlantic belt, from Virginia to Gaspé, as so abundantly established by the concurrent testimony of the Messrs. Rogers, Mather, Logan, and Emmons, already set forth. (§ 16, 72, 75, 109, 110, 177–179.)

§ 229. The normal position of the Sillery is, according to this view, seen to the south-east of Pistolet Bay, where the Sillery sandstones succeed to the crystalline rocks. Sedimentary beds of this kind take their character from the adjacent crystalline formations, and as the serpentinic, hornblendic, and chloritic rocks furnish, by their disintegration and decay, very different materials from the Laurentian gneisses of the Labrador coast, we find the Sillery sandstones and shales unlike the basal beds of that region, or of New York, and central Canada. It will be recollected that Emmons, in describing the Upper Taconic (Quebec) series, asserts that its basal beds are greenish chloritic sandstones and conglomerates, formed from the ruins of the crystalline rocks, and sometimes seen to rest directly upon them. (§ 107.) As the results of repeated dislocations, with upthrows in the eastern side, however, the whole order is generally, according to him, apparently inverted; the black fossiliferous shales of the summit appearing to dip eastward beneath all the other members, and the greenish sandstones seemingly overlying the whole, as seen in the Granville section. (§ 107–110.)

§ 230. The present writer urged, in 1872, that the Levis limestones, which apparently correspond to the Tremadoc rocks of Great Britain, occupy in the Quebec section a position nearer to the Sillery than does the graptolitic zone, which is clearly the equivalent of the less ancient Arenig or Skiddaw rocks; from which follows the stratigraphical inversion of the whole series. (Chem. and Geol. Essays, pages 412–413.) This view was shared by Mr. Billings, who, in a private communication, in January, 1876, shortly before his death, informed the writer that the *Obolella pretiosa* of the Sillery is apparently identical with *O. maculata*, Hicks,

from the Menevian of Wales. He had also recognized *Orthis Hicksii*, Salter, a Menevian species, in the Lauzon, or so-called Lower Potsdam beds of Bic Harbor. (§ 223.)

§ 231. The north-western limit of the strata of the Quebec group, in Canada, is nearly defined by a line running from Cape Rouge, in the vicinity of Quebec, to the northern extremity of Missisquoi Bay, on Lake Champlain. The rocks to the south-east of this line, including alike the fossiliferous strata, and the crystalline rocks of the Notre Dame range, supposed to be the same strata in an altered condition, were described by Logan as being arranged "in long, narrow, parallel, synclinal and anticlinal forms, with many overturn-dips. The latter circumstance makes it difficult to determine which of these folds are synclinal, and which anticlinal, inasmuch as the outcrops in both cases present a similar arrangement. The weight of evidence, however, goes to show that the strata dip to the centers of the areas about to be described, and they will, therefore, be designated as synclinals." They were declared, in the region in question, to be three in number, of which the first, or north-western one, included the uncrystalline strata already described in some detail, as seen near Quebec, at St. Flavien, on the St. Francis, at Acton, Upton, and Wickham, at Granby, Farnham, Bedford, and Phillipsburg. (Geology of Canada, pages 234 and 790, and Report for 1863–66, pages 29–39.)

§ 232. The evidence above alluded to was that deduced from the section near Quebec, according to which it was supposed that the Sillery sandstones were the highest rocks, and appeared only in the deeper parts of the first synclinal, which was partially divided by subordinate anticlinals into lesser basins. Certain carbonaceous slates, with thin beds of sandstone and impure limestone, which appear upon the supposed anticlinals, were, by Logan, conceived to be older than the Quebec group, and referred by him to the Potsdam. These, however, were found at Farnham to contain many organic remains, among which, according to Billings, are trilobites belonging to the genera *Ampyx*, *Dalmanites*, *Lichas*, *Triarthrus*, and *Agnostus*, together

with undescribed graptolites, a *Leptaena* like *L. sericea*, and a *Ptilodictya* like *P. acuta*. These forms, it was said, are not what "might be expected in the Potsdam formation, so that the Farnham slates, with similar ones in other localities, may be brought into position by some of the many complicated dislocations which affect the strata. Except, however, where such fossiliferous strata are known to occur, the black slates and limestones will be provisionally described as older than the Quebec group." (Geology of Canada, pages 234, 236, 239, 240.) Subsequently, however, Logan declared with regard to these black slates and limestones, supposed to be related to the Potsdam group, that it "appears to be difficult to separate them from the Phillipsburg rocks, and these being paleontologically connected with the lower 1,285 feet of the Levis series, the whole naturally constitutes one group." The original Levis formation was now first divided, and it was said that the "lower or Levis division comprehends the Phillipsburg series, the black shale above it, and the lower 1,285 feet of the Orleans section." The remainder of this last was called Lauzon. (§ 203.) (Report for 1853–66, pages 30–31.) The pages here quoted, though bearing the name of Mr. James Richardson, were written by Sir W. E. Logan.

§ 233. The black slates or shales, now included in the Levis formation of the Quebec group, (and placed higher than the Phillipsburg limestone,) were thus the same which, from their relations to the folded strata in the supposed north-western synclinal, were at one time conceived to underlie the whole Levis or Orleans section, and were still placed at or near its base. From their fossils, however, these slates belong to a horizon above that assigned to the Quebec group, and corresponding to the Trenton, or the still higher members of the Champlain division. We have thus a fourth fauna included in the Levis formation, (§ 224.) If, however, as we have endeavored to show, the position of these black shales is really at the summit and not at the base of the so-called Quebec group, which is an inverted series, the anomaly disappears, and we have, in ascending order:—1°, the Sillery sandstones; 2°, the trilobitic beds of

Levis and Phillipsburg; 3°, the Phyllograptus shales of Quebec; and 4°, the black shales of Farnham;—in which the succession is in accordance with the well known facts of paleontology.

§ 234. We may here notice the judgment of Prof. James Hall at this stage of the inquiry. He had hitherto employed the name of the Hudson River group as synonymous with the Loraine shales; but in 1862, in a note to his *Geology of Wisconsin*, page 443, he referred to the evidence of organic remains recently found in the Hudson River slates in Vermont and Canada, "which prove conclusively that these slates are, to a great extent, of older date than the Trenton limestone," although probably posterior to the Potsdam. He remarked, moreover, that "the occurrence of well known forms of the second fauna—*Leptæna sericea*, *Orthis testudinaria*, *Asaphus* (*Isotelus*), *Trinucleus*, etc.—in intimate relation with, and in beds apparently constituting a part of, the series along the Hudson River requires some explanation. Looking critically at the localities in the Hudson valley which yield these fossils we find them of limited and almost insignificant extent. Some of them are at the summits of elevations which are synclinal axes, * * where the remains of newer formations would naturally occur. Others are apparently unconformable to the rocks below, or are entangled in folds of the strata, * * while the enormous thickness of beds exposed is almost destitute of fossils." The graptolites of the Hudson valley, "which have hitherto been referred to the age of the other fossils found in the small outliers, or to the second fauna, in reality hold a lower position, and belong to the great mass of slates below."

He concluded that, inasmuch as the Hudson River rocks, in their typical localities, are, as a body, older than the Trenton limestone, which is itself older than the Loraine shales, and the shales and sandstones of Pulaski, "the term Hudson River group cannot properly be extended to these rocks, which, on the west side of the Hudson, are separated from the Hudson River group proper by a fault

not yet fully ascertained." See further § 237 and for the Pulaski rocks the note to § 249.

§ 235. There are not wanting evidences elsewhere that the fauna of the upper half of the Champlain division is included in this disturbed belt. The observations of the Rev. Augustus Wing, and those of Mr. Billings, in Vermont, which are to the point, were described by the present writer in a communication on the Geology of Vermont, read before the American Association for the Advancement of Science, at Chicago, in 1868. In a section from Crown Point, in New York, eastward across Lake Champlain to Bridport, in Vermont, the western part exhibits the whole succession of the Champlain division, from the Potsdam sandstone to the Loraine shales, which are overlapped by the Red sandrock, as already described (§ 116). This, dipping to the east, is overlaid by a great mass of limestones, seen in Sudbury, which yielded to Wing and to Billings the fauna of the Calciferous sand-rock, with other forms like those of the Levis limestone. Next in ascending sequence, also in Sudbury, was found a mass, estimated at not less than 2,000 feet, of limestones holding, in abundance, the fauna of the Trenton, and probably including that of the Chazy. To the east of this, again, a fault, marked by a ravine, brings up against the Trenton the Levis limestone, from which Mr. Billings obtained numerous characteristic fossils, including *Bathyurus Saffordi*. These fossils abound in Sudbury, Cornwall, Middlebury, and Brookville, where, according to him, they are closely associated with the white marbles quarried in this region. (Amer. Jour. Science [2], XLVI, 227.) This succession recalls the section in Newfoundland (§ 220) with forms apparently of Trenton age, and raises the question whether a careful study of the latter locality might not show the presence of the higher members of the Champlain division.

§ 236. The strata in this section examined by Wing and Billings, appear in their normal order, and, though affected by undulations, and by great up-throws on the eastern side, are not inverted. Further northward, however, Logan found remarkable examples of inversion, one of which is

seen near Highgate Springs, where the Trenton limestone, on the west side of an anticlinal, becomes vertical, and in places assumes an eastward dip. About eight miles further south, at Smith's lime-works, the Trenton limestone is overturned and overlaid in succession by the Black River limestone and by a series of sandstones and dolomites regarded as belonging to the Chazy. The whole of this inverted series, measuring about 600 feet, has an eastward dip, ranging from 45° to 75° beyond the perpendicular. Within a distance of 150 yards to the east, according to Logan, appears the Red sand-rock, with a gentle dip to the east. It here consists of red and white sandy dolomites, interstratified with dark-colored shales, in both of which are found the characteristic fossils of the Lower Potsdam, the whole series having a thickness of 2,200 feet. For an account of these inverted sections, see Geology of Canada, pages 275–280, and also page 855, where designs of them, drawn to a scale, are given.

§ 237. In 1863, Logan, in company with Professor James Hall, examined the rocks of eastern New York which had been designated by Eaton as Argillite and Transition Graywacke, (§ 61;) by Mather as belonging to the Hudson River group (Loraine,) and the Oneida and Medina formations, (§ 75–77;) by Emmons, first assigned to the same horizon, (§ 94,) and subsequently regarded as a great and peculiar development of strata of the age of the Calciferous sand-rock, (§ 96,) which he afterwards called, successively, the Taconic slates, (§ 103,) and the Upper Taconic series, (§ 107–108.) These rocks, described by Logan as consisting of greenish sandstones and conglomerates, with shales, sometimes red and green, and with shaly and concretionary limestones, including the Sparry lime-rock of Eaton, were declared to belong to the Quebec group. They were described as occupying nearly the whole of Rensselaer, Columbia, and Dutchess counties; the Sillery formation being largely developed in the first-named county, but scarcely extending south of it. To the westward, in approaching the river Hudson, these rocks were replaced by the lithologically distinct and more recent strata of the Loraine formation, a narrow belt of which was traced along the east side of the river to a point a little

above Hyde Park, where the boundary between the two formations crosses to the west bank, and the slates and limestones of the Quebec group thence occupy both sides of the river down to the Highlands, which were declared to be of Laurentian age. The results of these investigations are stated in a note prepared by the present writer, with the approval of Sir William Logan, and published in the *Canadian Naturalist*, in 1864, (vol. I, page 369.) They are also embodied in the geological map of Canada, (§ 44.)

§ 238. What were the relations between the older rocks, whether called Lower Potsdam or Quebec group, and the higher members of the Champlain division found along their western border? We have seen that Logan had formerly supposed, with Mather, that this line marked a great anticlinal axis (§ 195.) The later view of the Quebec group, arrived at by Logan, in 1861, made this hypothesis no longer tenable, and a new one was put forward by him in 1861, in the *Canadian Naturalist*, (vol. VI, page 199, which is set forth in the Geology of Canada, (pages 294–297.) The new hypothesis supposed that the whole series of rocks, including the Potsdam and Quebec groups, and the succeeding Trenton, Utica, and Loraine formations, had been laid down conformably, and without disturbance. Logan conceived that the deposition had taken place along the south-east border of a Laurentian continent, and that while the great accumulations of the Potsdam and Quebec groups were going on, the typical Potsdam sandstone and the Calciferous sand-rock of the New York series were laid down over an adjacent terrace or shallow basin, which was submerged at intervals. It was not until the close of the Champlain period, that a great break, with an uplift of 7,000 feet, was imagined to have brought up the lower strata on the south-east side of the dislocation, causing them to over ride the broken edges of the higher formations. This supposed line of break and upthrow of 7,000 feet, was coincident with the former anticlinal axis of Mather and Logan (§ 69–71, 195), and was now said to extend from Gaspé to Alabama.

§ 239. Such a dislocation, so near the continental border,

it was sought to explain by assuming for the shore of the ancient continent, a great height and a very steep inclination. In the words of Logan: "During the Potsdam period, in the neighborhood of Quebec, we see that the surface of the quartzose gneiss now supporting the Trenton limestone at the Falls of Montmorenci, must have been 7,000 feet above the gneiss under the Island of Orleans, while the distance between the two positions does not much exceed a mile and a half. This would give a slope of nearly 45°, and perhaps it would not be extravagant to take this as representing the inclination along the whole line to Alabama. As the Potsdam and Quebec groups accumulated, their edges would abut against this slope, and ultimately both these and the early shallow-water deposits on the higher terrace (the typical Potsdam sandstone and Calciferous sand-rock) would be covered over" by the Trenton limestones and the Utica and Loraine formations. This supposed condition of things was illustrated by an ideal diagram (page 296), in which the whole succession, including the black shales of the Potsdam at the base, are represented as horizontal strata, the Potsdam being overlaid by the Quebec group, which, in its turn, is covered by the Trenton and the higher formations. On page 234 another diagram represents these deposits after the supposed break, in a section from Montmorenci to Orleans Island.

§ 240. This explanation requires, according to the admission of Logan, the extraordinary condition of a mountain-range stretching from Gaspé to Alabama, rising from the sea with "a slope of nearly forty-five degrees" to a height of 7,000 feet, which gradually subsided, as accumulation went on along its base, until it was completely submerged. The facts of the case, however, do not require any such geographical improbability to account for them, and a simpler explanation of the problem is found in the existence of an unconformity between the Trenton limestone and the older members of the paleozoic series.

§ 241. Movements of the earth's crust, resulting in folded and inverted strata, have demonstrably taken place along the Atlantic belt at several periods. The Silurian lime-

stones, (including those of Niagara and Lower Helderberg age, which constitute the Gaspé limestones of north-eastern Canada (§ 175),) are found near Montreal, resting transgressively upon the eroded edges of the Champlain division, and further east in like manner, both upon the strata of the Quebec group and upon the crystalline rocks of the Notre Dame range. Throughout the Atlantic belt, in Canada, these Gaspé limestones are folded, faulted, often at high angles, and sometimes vertical and even inverted. (Geol. of Canada, page 429.) In Gaspé, where they are conformably overlaid by the Devonian sandstones, fragments of both of these enter into the conglomerate of the Lower Carboniferous, which rests upon them unconformably. This, in its turn, is more or less disturbed, and, in parts of New Brunswick, its strata appear nearly or quite vertical in attitude. There is, in this region, a want of conformity between the Lower Carboniferous and the Coal measures, which are, themselves, often much disturbed, and bear upon their upturned edges beds of Triassic sandstone, which, itself, is sometimes raised to an angle of 45°. We have thus along the Atlantic belt, in the provinces of Quebec and New Brunswick, evidences of at least five periods of movement, marked by parallel foldings of the strata and by unconformity subsequent to the deposition of the rocks of the Champlain division, namely: 1, post-Siluro-Cambrian; 2, post-Devonian; 3, post-Lower Carboniferous; 4, post-Carboniferous; 5, post-Triassic.

§ 242. Analogy would lead us to suppose that similar movements, giving rise to unconformity, might have occurred during the Cambrian period. Logan himself, after having maintained the contrary, conjectured a discordance between the Potsdam and the Quebec group in Vermont, (Amer. Jour. Science [2], XLVI, 225,) and subsequent researches, in 1868, on the south shore of the St. Lawrence, below Quebec, led him to admit such an unconformability in that region. (§ 223.) The evidence of a want of conformity between the Birdseye and Black River limestones, (the basal portion of the Trenton) and the inferior members of the Champlain division, is in great part indirect, but is

cumulative. There exists, in the first place, a complete paleontological break at this horizon. According to the careful determinations of Mr. Billings up to 1872, when they were furnished by him to the present writer, we find in the Chazy limestone of the Ottawa basin ninety species of organic remains, of which twenty-two are known to pass upwards into the directly overlying Birdseye and Black-River limestones; while of the forty-four species found in the Calciferous of that region but two are met with in the Chazy. This latter break is elsewhere filled by the Levis (and Phillipsburg) limestones, containing twelve species from the Calciferous and five from the Chazy; but of the whole fauna of the Levis limestones, and the Quebec Phyllograptus shales, amounting in all to more than 200 species, not a single one, according to Mr. Billings, has been met with in the basal beds of the Trenton limestone group. (Hunt. Chem. and Geol. Essays, page 412.)

§ 243. The interposed Chazy limestone, which thus forms a connecting link between the Calciferous and the Trenton, bears evidence of a period of disturbance. As described by Logan, at Grenville in the Ottawa basin, it includes a mass of fifty feet of shales and sandstones, while its base is a conglomerate of limestone pebbles, resting on a fossiliferous magnesian limestone, regarded as the Calciferous sand-rock. Moreover, in Herkimer county, in the Mohawk valley, according to Prof. James Hall, the Chazy is absent, and the basal beds of the Trenton rest directly upon the Calciferous sand rock. (Ibid. page 414.)

§ 244. Beyond the limits of the Ottawa basin, to the west as far as Lake Huron, the Trenton limestone is found resting on the Primary crystalline rocks, while from the vicinity of Berthier, about fifty miles north-east of Montreal, to Quebec, and beyond to Malbaie, the same is true. Beds of quartzose conglomerate, and sandstones sometimes occur at the base of the limestone in this region, but where these have yielded fossils, as at Malbaie, they are found to belong to the inferior beds of the Trenton. Again, at Lake St. John, on the Saguenay, the Trenton is found to rest directly on the crystalline rocks.

§ 245. From these facts it is plain that after the deposition of the Calciferous and Chazy formations, and before the time of the Trenton, there was a considerable continental movement, by which the deep Trenton sea was widely spread over regions which had not been submerged in the earlier part of the Champlain period, and deposited its limestones to the north and east, far beyond the limits of the immediately preceding formations. (§ 99.) Still further movements took place over parts of the area in question, as is shown by the direct superposition of the Utica formation upon the Primary rocks at the base of the Adirondacks, (§ 101,) and the discordant superposition of the Utica and Loraine upon the lower members of the Champlain division near Ottawa. (§ 100.)

§ 246. The movements which resulted in the overlapping by the Trenton of the older members of the Champlain division, do not, it is true, necessarily imply discordance, but they make it possible, and, when taken in connection with the complete paleontological break, highly probable. When it is considered that the alternative of denying a want of stratigraphical conformity at this horizon is the acceptance of the hypothesis of Logan, (§ 238,) few, we think, will hesitate to admit that the period immediately preceding the deposition of the Trenton must have been marked, along the Atlantic belt, by a movement of the earth's crust, which resulted in the uplifting, faulting, folding, and frequent inversion of that great mass of sediments along the western base of the Primary rocks, which constitutes the Upper Taconic series. The Trenton, Utica, and Loraine formations would then be laid down over the disturbed surface of these, precisely as over the still older rocks of the Laurentides. In this connection must be considered the statement of Emmons, that small areas of the last two named formations rest unconformably upon the Taconic rocks, near Chatham in eastern New York. (§ 97.)

§ 247. These newer rocks, including the Trenton limestone group, must necessarily have shared in all the later movements of the Atlantic belt, which, as we have shown, continued at intervals into Mesozoic time, and involved even

Devonian and Carboniferous strata. The similar foldings and inversions of the upper members of the Champlain division along the western borders of the Upper Taconic series, as observed by Logan, are completely analogous to those exhibited by the Auroral limestone along the western base of the Laurentian of the South Mountain, in Pennsylvania and New Jersey, as described by Rogers, (§ 16;) and the facts observed by Mather in eastern New York (§ 72) are of the same order. The phenomena, in many cases, show that the older rocks did not act merely as passive barriers in these movements, but themselves yielded to the lateral pressure, so that they over-ride the newer strata, which pass beneath them.

§ 248. The boundary between the Upper Taconic or Quebec group, and the younger members of the Champlain, is, in this view, neither an anticlinal axis, as taught by Mather, and by Logan, previous to 1861; nor yet a line of fracture and great uplift, as subsequently maintained by the latter; but was primarily a line of contact, where the Trenton, and the succeeding Utica and Loraine formations, rest unconformably upon the disturbed strata of the Upper Taconic series. The relations of the two have been more or less complicated and obscured by subsequent movements, involving alike the younger and the older series, as above described, and giving rise to many minor anticlinals, inversions, and uplifts, which, although secondary and subsidiary in character, seem, at first sight, to afford some justification for both of the hypotheses previously proposed. The view that the relations of these two series is primarily one of stratigraphical discordance, was advanced by the present writer in 1871 and 1872. (Chemical and Geological Essays, pages 263, 413.)

CHAPTER IV.

HISTORICAL SKETCH CONTINUED.

§ 249. Before proceeding to a further discussion of the various rock-formations found beneath the horizon of the Trenton limestone group, it becomes necessary to consider briefly the nature, the succession, and the paleontological history of the lower paleozoic rocks in Great Britain and in continental Europe, and to compare them with those of North America. To this end, a table, prepared with the aid of one published by Hicks, in 1875, is subjoined, in which the principal divisions of these rocks in Great Britain, up to the summit of the Bala group, (which is regarded as corresponding with that of the Loraine shales,*) are enumerated in ascending order, the thickness of each being given. (See, in this connection, the papers of Hicks, Quar. Jour. Geo-

*The Loraine shales of Emmons constitute the summit of the Siluro-Cambrian in the United States. They were called by Vanuxem the Pulaski shales, and made by him the upper member of the Hudson-River group, while the Frankfort sandstones and shales, which he regarded as a lower member of the same group, were by him confounded with the Upper Taconic rocks. This question will be discussed at the end of the present chapter.

logical Society, vols. xxix, 42, and xxxi, 192; also Hunt, Chemical and Geological Essays, pages 384–386.)

LOWER PALEOZOIC ROCKS IN WALES.

		Feet.
VII.	BALA group or Caradoc, varying in thickness from 3,000 to	12,000
VI.	LLANDEILO group, often much exceeding . . .	3,000
V.	ARENIG group, divided into Upper, 1,500 feet; Middle, 1,500 feet, and Lower, 1,000 feet. The lower division of the Arenig abounds in graptolites, and is equivalent to the Skiddaw slates. It corresponds to what in North Wales has been called Upper Tremadoc,)	4,000
IV.	TREMADOC group, ...	1,000
III.	LINGULA-FLAG group, including Upper or Dolgelly, 600 feet; Middle or Festiniog, 2,000 feet; and lower or Maentwrog, 2,500 feet. (The lower and middle divisions of the Lingula Flags are equivalent, respectively, to the Hollybush sandstone and to the Olenus slates of Malvern,)	5,100
II.	MENEVIAN group, ...	600
1.	LONGMYND group,, including the Llanberris slates and the Harlech sandstones, often much exceeding	4,000

§ 250. The above series represents the whole of the Cambrian of Sedgwick, as defined by him in 1838. He subsequently divided it into the Lower Cambrian or Bangor group, (I); the Middle Cambrian or Festiniog, (II, III, IV,) and the Upper Cambrian or Bala group, (V, VI, VII,) which embraced the Bala, Llandeilo, and Arenig of the present scheme. When first named, no organic remains were known in Sedgwick's first and second groups, and the third was, by an error of Murchison's, claimed as a lower member of his Silurian system, (which properly includes the succeeding Llandovery, Wenlock, and Ludlow formations.) He, thereupon, called the Upper Cambrian group of Sedgwick, Lower Silurian, a name which was adopted by the greater number of geologists, both in Great Britain and North America. The name of Cambro-Silurian, or better that of Siluro-Cambrian, has been by many, however, used to designate the Upper Cambrian of Sedgwick, and will be so employed in the following pages.

§ 251. Murchison assumed that the Silurian, as thus extended downward by him, represented the dawn of life, and, when, at a later date, organic remains, belonging to the so-called Primordial zone of Barrande, were found in lower portions of the Cambrian, attempted to annex these portions to his Silurian system under the name of Primordial Silurian; restricting the name of Cambrian to the Longmynd group, which was, at that time, still regarded as non-fossiliferous. This latter innovation of Murchison's, though adopted by Barrande, and by the geological survey of Great Britain, who have been copied in Canada and the United States, is with reason rejected by most other British geologists, and by those of Sweden, who retain the name of Cambrian for both the Lower and the Middle groups of Sedgwick. Belt, (who with Hicks, has greatly advanced our knowledge of these older rocks in Great Britain,) includes I and II of the above table in the Lower Cambrian, while he gives to III, IV, and V the name of Upper Cambrian, conceding for the original Upper Cambrian of Sedgwick, (the Siluro-Cambrian), the name of Lower Silurian, a nomenclature which was adopted by Lyell. In these pages, while maintaining the name of Siluro-Cambrian, the terms Lower and Upper Cambrian will be used in the sense in which they are employed by Belt and by Hicks.

§ 252. The whole of the Lower and Upper Cambrian in Wales, amounting to over 10,000 feet, consists, so far as known, of sandstones, conglomerates, and shales. The latter are sometimes calcareous, but no limestone beds have been found below the Llandeilo group of the Siluro-Cambrian. The Upper Cambrian series, which has been carefully studied and sub-divided by Belt, presents, according to him, a remarkable case of inversion at Dolgelly, in North Wales, where the strata are completely overturned, so that the apparent succession, in ascending order, gives the Arenig, Tremadoc, Dolgelly, and Festiniog formations. Great dislocations occur in South Wales, by which the Tremadoc, and even the Arenig rocks, are let down against the Harlech beds of the Longmynd group. For a more detailed account of the whole question of the discovery and the nomencla-

ture of these older rocks, the reader is referred to the author's essay on The History of Cambrian and Silurian. (Chem. and Geol. Essays, pages 349–425.)

§ 253. The fauna found in the Menevian of South Wales, including species of *Paradoxides*, *Microdiscus*, *Conocoryphe*, (= *Conocephalus* and *Conocephalites*,) and *Agnostus*, is continued downward, with but little change, through more than 2,000 feet of the underlying Harlech rocks, which are, moreover, connected with the Menevian by several species of brachiopods common to both, and have here a measured thickness of nearly 4,000 feet. The lower portion of the Harlech, which consists chiefly of red and green sandstones, with slaty beds, resting unconformably upon crystalline rocks, and measuring 1,600 feet in thickness, has, however, yielded no trilobites, though containing *Leperditia*, *Discina*, *Obolella*, and *Lingulella*. This absence of trilobites from the base of the Cambrian seems to mark a distinct zone, of which we have further evidences both in Scandinavia and in Bohemia.

§ 254. We find in Sweden the whole succession of British Cambrian and Silurian rocks represented by about 1,000 feet of horizontal strata, which, according to Linnarsson, may be thus designated, as numbered in descending order. (Geol. Magazine, 1876, vol III, page 240.)

1. Encrinurus beds.
2. Leptæna limestone.
3. Upper Graptolitic schists.
4. Brachiopod schists.
5. Trinucleus schists.
6. Chasmops limestone.
7. Middle Graptolitic schists.
8. Orthoceras limestone.
9. Lower Graptolitic schists.
10. Ceratopyge limestone.
11. Dictyonema schists.
12. Olenus schists.
13. Paradoxides schists.
14. Fucoidal sandstone.
15. Eophyton sandstone.

—. Unconformable crystalline rocks.

§ 255. The Olenus schists, which, in some parts of Sweden, are not over forty or fifty feet in thickness, contain, it is said, the equivalents of the three divisions of the 5,000 feet of the British Lingula flags, and are underlaid by the Paradoxides schists, which are by Linnarsson regarded as representing both the Menevian and the trilobitic portions of the Harlech. The sandstones 14 and 15, which form the lower divisions of the Swedish Lower Cambrian, may, there-

fore, reasonably be supposed to represent the inferior portion of the Harlech. They measure about 100 feet in middle Sweden, but are thicker both to the north and the south.

§ 256. These sandstones, according to Linnarsson, are marked by the absence of trilobites, and in Sweden the upper division, the Fucoidal sandstone, contains, besides impressions of algæ, and tracks and furrows of worms and other animals, only two species of Lingulellidæ. The underlying Eophyton sandstone has yielded a more marked fauna; besides *Cruziana*, *Harlania* (*Arthrophycus*) and *Eophyton*, all of which Linnarsson regards, with reason, as but casts and tracks, of little significance, we find a brachiopod, provisionally called *Obolus* or *Lingula monilifer*, unknown elsewhere, which will probably constitute a new genus, besides *Hyolithes levigatus* and *Astylospongia radiata*, which have apparently "no near relatives." It is from this Eophyton sandstone that Torell has described vertical funnel-shaped casts, occurring in groups, which he regards as formed by two species of animals, named by him *Monocraterion* and *Diplocraterion*. Around the summit of the former are impressions of what seem to be tentacles.

§ 257. The corresponding rocks in southern Norway are, by Kjerulf, divided into seven groups or stages. Stage 1 of this author is a great mass (2,000 feet or more) of red and gray sandstones and conglomerates, (sparagmites,) with clay-slates of the same color, besides a bluish quartz-rock, quartzy talcose slates, and considerable beds of limestone and dolomite; the whole without observed fossils, and called by Kjerulf, Lower Taconic. Stage 2 consists of clay-slates and limestones, with *Dictyonema* and *Olenus*, and is designated, by Kjerulf, Upper Taconic, to which period, moreover, he refers, with some doubt, a great mass of hornblendic and other crystalline schists. Of the succeeding groups, called by him Silurian, Stage 3 includes the older Graptolitic schists and the Orthoceratite limestone; Stage 4, the Chasmops limestone; Stage 5, calcareous sandstones and shales, and Stages 6 and 7, the newer Graptolitic schists and Pentamerus limestones. The relations of these stages with the Swedish series are, for the

most part, evident. Stage 1 is supposed to be equivalent to the basal sandstones of Sweden; but, from their thickness and their lithogical peculiarities, these Lower Taconic rocks of Kjerulf may not improbably include also a still lower horizon.

For the facts with regard to these rocks, the present writer is indebted, in part, to the unpublished maps and sections exhibited by the geological survey of Norway, at Philadelphia, in 1876. He has also to acknowledge personal communications on the geology of these regions from his friends, Dr. Kjerulf and Dr. Torell, the directors, respectively of the geological survey of Norway and Sweden.

§ 258. In Russia, a band of pyroschists which, by the presence of *Dictyonema flabelliforme*, are identified by Linnarsson with the Dictyonema schists of Sweden, (regarded as the equivalent of the Tremadoc group of Wales,) extends from St. Petersburg along the coast of Esthonia, and has beneath it several hundred feet of friable sandstones and shales, including the Obolus or Ungulite grit. But little, however, is as yet known of the fauna of these basal sandstones.

§ 259. In Bohemia, the fauna of the so-called Primordial zone (Stage C of Barrande,) is, according to Linnarsson, most closely related with that of the middle portions of the Paradoxides schists of Sweden. Between this and the Stage A of Barrande, which consists of crystalline rocks, is his Stage B, a series of sandstones and conglomerates which contain the casts of double tubes, supposed to be due to annelids. Thus it appears that in Bohemia as in Scandanavia, and in Wales and Canada, there exists a series of sandstones and slates beneath the lowest recognized trilobitic horizon.

§ 260. We may now inquire what data the Cambrian rocks of Great Britain and of continental Europe can afford for a comparison with those of North America? The genera of trilobites found in the Longmynd are *Agnostus*, *Conocoryphe*, *Microdiscus*, *Paradoxides*, and *Plutonia*, all of which, with the exception of the last, occur in the Menevian, with the addition of *Arionellus*. The genus

Olenus extends from the base of the Lingula flags to the Lower Arenig, which latter also contains *Ampyx*, *Asaphus*, *Calymene*, *Cheirurus*, and *Dikellocephalus*. The last-named genus, according to Hicks, is not found below the Arenig, the forms hitherto referred to it in the Tremadoc and the Lingula flags belonging to the allied genus *Neseuretus*. The genus *Conocoryphe* is confined, so far as known, to the Longmynd and Menevian, and the various species referred to it from higher horizons should, according to Belt and Hicks, constitute a new genus. *Agnostus*, which extends from the Longmynd to the Arenig, is thus the only genus of trilobites which connects the Lower with the Upper Cambrian.

No gasteropods have been found below the Middle Arenig, and no lamellibranchs below the Tremadoc. *Orthoceras* occurs in the Tremadoc, and with *Cyrtoceras* in the Lower Arenig. *Dendrocrinus* and *Palæasterina* have been found in the Tremadoc, while a cystidean is met with in the Menevian, and in Sweden a form of star-fish occurs in rocks regarded as the equivalent of the Longmynd. The genus *Obolella* extends from the Longmynd to the Arenig. Most of the above facts relating to the Cambrian fauna of Wales are taken from the late papers of Hicks, already cited.

§ 261. The study of the graptolites, as a means of fixing geological horizons, has, of late, attracted considerable attention, and the researches of Linnarsson have recently enabled Nicholson to make very satisfactory comparisons between the graptolite-bearing strata of Sweden and those of Great Britain. (Geol. Magazine for 1876, Vol. XIII, page 245.) There are, according to Linnarsson, five graptolitic zones in the paleozoic rocks of Sweden, the *first* of which, in ascending order, (referring to the table in § 254), is that of the Olenus and Dictyonema schists (12, 11), (characterized by *Dictyonema flabelliforme, and Dichograptus tenellus*,) regarded by Nicholson as equivalent to the Tremadoc group. The *second* zone, designated by Linnarsson as the Lower Graptolitic shales (9), contains *Tetragraptus*, *Didymograptus*, and *Phyllograptus*. These are the undoubted equivalents of the Skiddaw (Cumberland) and Quebec

graptolitic shales, and correspond to the Arenig group in Wales, which contains them throughout, though most abundantly in its lower divisions. The *third*, or Middle Graptolitic schists (7) correspond, according to Nicholson, to those found in the lower portions of the Moffat series in the south of Scotland, and the *fourth* and *fifth*, (included in the Upper Graptolitic schists, 3,) to the superior portion of the same series.

The schists of division 3, in Sweden, include, according to Nicholson, two distinct graptolitic zones, the lower part containing the forms of the Coniston mudstones of Cumberland, regarded as belonging to the Siluro-Cambrian; while the upper part yields the forms of the Coniston grits, the equivalents of the May-Hill sandstone, above the Bala group, and belonging to the true Silurian. This upper portion, which constitutes the *fifth* graptolitic zone, is well developed in Norway. It would be foreign to the purposes of our history to enter into further details with regard to these higher graptolitic zones, which apparently correspond to those of the Utica and Clinton formations of North America.

§ 262. Returning now to the lower paleozoic rocks of the New York series, we have seen that Billings, conceiving that the Olenellus beds of Vermont and Newfoundland belong to a lower horizon than the typical Potsdam sandstone of New York, designated this as Upper Potsdam. This formation, as is well known, is traced continuously from the southern base of the Adirondacks into the Ottawa basin in central Canada; to the east and west of which it disappears along the northern outcrops of the paleozoic series. So far as yet observed, it rests in a nearly horizontal attitude upon the Eozoic crystalline rocks, and in Hemmingford Mountain, near the north-west border of Lake Champlain, where it reaches its greatest observed thickness, of about 600 feet, includes beds of a conglomerate holding pebbles of quartz, and others of green and blackish argillite. The rock is sometimes a friable sandstone, and at other times, a hard and almost vitreous quartzite, white, and rarely red in color. Towards the summit it becomes interstratified with dolo-

mitic layers, marking its passage into the succeeding Magnesian limestone, which, from its rough surface and its feeble effervescence with acids, was early misnamed the Calciferous sandrock. It is, however, a true dolomite, granular in texture, and abounding in druses holding crystals of quartz, calcite, sulphates of baryta and stroutia, and in some places small nodules of gypsum. It often passes towards the summit into an impure argillite, and has a maximum thickness of 300 feet.

§ 263. The organic remains found in the Potsdam of the above defined area, are few in number; besides two species of *Lingula*, it has yielded at Keeseville, New York, a trilobite, at first called a *Calymene*, but subsequently described by Bradley as *Conocephalites* (*Conocoryphe*) *minutus*, which is associated with a species of *Hyolithes*, a *Pleurotomaria* and crinoidal fragments. A species of *Dikellocephalus* like *D. Sesostris* is, according to Billings, met with in the superior beds of the Potsdam, at Whitehall, New York, while at Beverley, Ontario, along with *Lingula acuminata*, are found a *Pleurotomaria*, an *Ophilela*, and two species of *Orthoceras*, besides marks of algæ. Billings, however, remarks that these beds should perhaps be included in the overlying Calciferous sandrock. In several localities in Canada, the beds of the Potsdam bear the tracks of large animals of several species, which have been named *Protichnites* and *Climactichnites*, both of which are regarded as probably due to crustaceans. (Pal. Fossils, I, pages 57, 59, 97, 198.)

§ 264. In addition to these, the upper part of the formation is found to be abundantly marked, over considerable surfaces, by a form described by Billings under the name of *Scolithus Canadensis*. "This species consists of cylindrical or irregular prismatic stems (or rather the cavities in the rock once occupied by such stems) from one to two lines in diameter, and from one to six inches in length, and either straight or more or less curved. In some specimens several of the stems are in contact with each other, and when this is the case, and the stems have an angular shape, they very much resemble the coral, *Tetradium*. The larger stems are

more often straight than the smaller. The individuals are usually scattered irregularly through the rock, lying in all directions." (Ibid., I, 96.)

The *Scolithus* appears on the weathered surface of the beds "in the form of small holes, which sometimes penetrate vertically to a depth of several inches, but on breaking up the rock they are found to be more or less curved in different directions, and often irregularly contorted, and intermingled with each other. The casts of the interior of these cavities, in freshly broken or unweathered specimens of the rock, usually appear as cylindrical or angular rods, (with three, four or five sides,) composed apparently of grains of sand cemented by a slightly calcareous matter, more or less tinged with oxyd of iron. The origin of these holes is not quite certain; some suppose them to be remains of fucoids, others of corals, while many are of opinion that they were the habitations of small burrowing marine or shore-frequenting animals. Whatever may have been their origin, they characterize only the upper part of the Potsdam sandstone. The original specimens, upon which the genus Scolithus was established, differ from those above described in being straight, and more decidedly cylindrical, and are therefore probably a distinct species." A figure of *Scolithus Canadensis* is given in the Geology of Canada, page 102, from which the above account is quoted.

§ 265. The name of *Skolithus* was proposed by S. S. Haldeman, in 1840, as the designation of a sub-genus of fucoids, and was applied by him to the cylindrical casts found in the Primal white sandstone at Chiques, on the Susquehanna. In 1847, Professor James Hall described *Scolithus linearis*, giving a figure of one specimen from the Susquehanna, of another from North Adams, Massachusetts, and of a third from a locality not named. It was said to be found rarely on Lake Champlain, but was referred to the [illegible]nd-stone, and declared to occur in sandstones [illegible] the base of the Green Mountains, as [illegible]w [illegible]sey, Pennsylvania, and Virginia. (Paleo[illegible]logy [illegible] New York, vol. I, page 2, and plate I, figs. 1 a—1 c.

§ 266. Markings called *Scolithus*, have since been looked

upon as evidences of existence of the Potsdam sandstone in various localities throughout the Appalachian valley, and in Pennsylvania were described by H. D. Rogers as characteristic of the Primal white sandstone, which was regarded as the equivalent of the Potsdam, (§ 4, 7, 9.) The name of *Tubulites* which, according to Rogers, was given to these markings in the annual geological reports of Virginia and Pennsylvania, was subsequently exchanged for that of *Scolithus linearis*. The original description of this species by Hall was amplified and augmented by Rogers, who describes it as "a nearly straight cylindrical simple stem-like impression, usually almost smooth, but in some specimens faintly waved or grooved transversely to its axis. Its diameter is from one eighth to one half an inch, its length from a few inches to two or three feet. Its position in the rock is invariably perpendicular to the bedding, suggesting the idea of perforations by some marine worms. One end of the fossil always terminates at the upper surface of the bed of sandstone inclosing it, and usually in a rudely-flattened knob or head, giving to the whole the likeness of a large long pin. This knob is probably a cast formed in the wide, conical, funnel-shaped mouth of a cylindrical perforation. Similar stem-like forms occur in some of the other sandstones of the higher Appalachian formations, but none are so well characterized as this species of the Primal white sandstone. An excellent locality is at Chiques, on the Susquehanna." A figure is given by Rogers of this fossil, which is also said to occur in great abundance in the Blue Ridge of Virginia. (Geol. Penn., II, 815.)

§ 267. In 1852, Hall described and figured, under the name of *Scolithus verticalis*, a form characterized as being smaller than *S. linearis*, and as penetrating vertically the beds of the Medina sandstone in Monroe county, New York. (Paleontology of New York, vol. II, page 6, and plate II, figure 3.) It was not until 1862 that Billings described *S. Canadensis*, (§ 264,) at the same time declaring with regard to *S. linearis*, "it is generally larger, and the stems are straight and parallel with each other," and adding, "I have seen no specimens of this species in the Canadian

rocks, though it occurs in the lowest red sandstone of Labrador, on the strait of Bellisle." This sandstone, already noticed, (§ 215) is below the Olenellus limestone, and of the *Scolithus* therein found Billings elsewhere remarks, that "it differs from the one so common in the Potsdam sandstone of Canada, in being larger and straighter. It is perfectly identical with that of the Upper Primal sandstone of Pennsylvania, and also with that of the Potsdam (Chilhowee) sandstone of Tennessee." (Pal. Fossils, III, 2, 96.)

§ 268. Several examples of *Scolithus* which the present writer has examined from the Potsdam sandstone of Wisconsin, appear to be identical with *S. Canadensis* and, though probably distinct, are much more like to the *L. verticalis* collected by him in the Medina (Levant) sandstone of Huntingdon county, Pennsylvania, than to the *S. linearis* found in the Primal white sandstone along the Susquehanna and the Schuylkill. Some specimens from these latter localities exhibit, in a marked manner, the transversely "waved or grooved" surface, noticed by Rogers, leading an eminent foreign geologist, who lately saw them for the first time, to take them for casts of crinoidal stems.

§ 269. Further investigations are however needed to clear up the history of *Scolithus*, and it would appear that even in the typical Potsdam sandstone there have been confounded under this name the marks of distinct and unlike objects. The sandstone which at Port Henry, New York, forms the base of the Champlain series is, in its lower portions, a strong, hard, massive, thick-bedded, dark bluish or iron-gray quartzite, with lighter gray layers, and includes thin blackish shaly partings. The higher portions are thinner bedded, light-gray and porous, and are made up of strongly coherent rounded agglutinated grains, with irregular interstices, the whole being silicious, and slightly stained with iron-oxyd. Hall has noted the same structure in the upper beds of the Potsdam in Iowa, and has well remarked that their appearance suggests that they were "largely formed from silica in solution, or from gelatinous silica." (Paleontology, Vol. III, page 4.)

§ 270. Some of these upper beds at Port Henry, lately

examined by the writer, abound in impressions evidently organic, which have been designated *Scolithus*. These appear upon the upper surface of the newly separated beds as cylindrical cavities, each enclosing a central tube made up, like the surrounding rock, of coherent silicious grains. These tubes are a millimeter in internal diameter, with walls half a millimeter in diameter, and a vacant space of the same dimension between the tube and the smooth surrounding walls of the cavity; though very fragile, the interior tubes were disclosed in oblique fractures of the rock to the length of a centimeter, without any marks of joints or septa. They exhibited, in some cases, traces of two concentric layers. The cylinders were seen to traverse vertically the beds for distances of two or three inches, but the lower portions were filled up and their internal structure was not apparent. The arrangement is such as would result from the enclosure in the rock of a cylinder having a central axis, with an intermediate space which became filled with silicious matter, the cylinder, and its axis being subsequently removed.

In weathered specimens, from which the internal tube has disappeared, the cylindrical cavities, more or less completely filled, resemble very much the burrowings of a worm, but in either condition they are evidently very distinct, both from the prismatic shapes noticed by Billings under the name of *Scolithus Canadensis* (§ 264,) and the transversely grooved cylindrical rods of the Primal white sandstone.

§ 271. We have already seen that, while the Potsdam sandstone graduates into the Calciferous sand-rock, the overlying Chazy formation gives evidence of a break in the succession of sediments; its base, in parts of the Ottawa basin, consisting of a limestone-conglomerate, resting on the Calciferous sand-rock. Elsewhere in this region, it appears as a silicious conglomerate, with quartz pebbles, nodules of phosphate of lime, (coprolites) and the characteristic fossils of the Chazy formation, resting directly on the Laurentian gneiss; while in Herkimer county, New York, the Chazy is absent from its place between the Calciferous and the Trenton. At Grenville, on the Ottawa, there is found

above the limestone-conglomerate of the Chazy about fifty feet of grayish sandstone, sometimes ripple-marked, and occasionally conglomerate. These are accompanied and followed by greenish fucoidal shales, above which, making the upper portion of the Chazy formation, is a reddish or grayish pure massive limestone, composed, in great part, of the crystalline remains of crinoids and cystideans, while other beds abound in brachiopods. These limestones, which are sometimes interstratified with dolomitic layers, have at Montreal, where they are largely quarried for building-purposes, a thickness of seventy feet, the aggregate of the whole Chazy formation in the region being about 150 feet.

§ 272. The Chazy, after disappearing beneath the border of the Trenton, a little to the north-east of Montreal, (§ 244,) re-appears 500 miles further on in the same direction, on the Mingan Islands in the gulf of St. Lawrence, where it is represented by a series of fossiliferous limestones, with some interposed sandstones and shales, the whole thickness being estimated at about 300 feet. The underlying beds, supposed to represent the Calciferous sand-rock, are also highly fossiliferous magnesian limestones, of which about 250 feet have been observed. (Geology of Canada, chapters VII and VIII.)

§ 273. In the northern part of Lake Huron, horizontal limestones, dolomitic at the base, and fossiliferous throughout, are found resting, at the Snake Islands, on the upturned Huronian strata, while at Lacloche Island, and further to the west, similar limestones repose upon horizontal beds of red and white sandstone, known as the St. Mary's sandstone. These limestones have yielded the organic remains of the Birdseye, Black River, and Trenton divisions of the Trenton group, and in Sugar Island, according to Professor Hall, have at their base some arenaceous and argillaceous beds, which contain the characteristic fossils of the Chazy formation. (Foster and Whitney, Geology of Lake Superior, II, 140.)

§ 274. To the south-west of Lake Superior, in Wisconsin, Minnesota and Iowa, in the upper Mississippi valley, we find repeated, with some variations, the rocks of the Cham-

plain division of the New York series. These rocks have been studied by David D. Owen, by James Hall, and later by Roland Irving. In Wisconsin, where these strata occupy a large area to the west and south of the crystalline rocks, the Potsdam sandstone is described as having a maximum thickness of about 700 feet, and as overlaid by the Lower Magnesian limestone of Owen. It however thins out to the northward, where the limestone rests directly on the crystalline strata. It was noticed by Hall that the upper part of the Potsdam becomes dolomitic, showing a passage to the overlying formation, and this transition has since been studied by Irving, in Dane and Columbia counties. He describes there 800 feet of sandstone, which have been penetrated in borings, and show more or less dolomitic admixture for the upper two thirds. Above this lie about thirty feet of a yellowish magnesian limestone, massive below and shaly above. It includes layers of green-sand, especially near its base, and in places abounds in trilobites, the most common of which is *Dikellocephalus Minnesotensis*. This division, called by Irving the Mendota limestone, is succeeded by thirty-five feet of sandstone, often purely silicious, but sometimes ferruginous and dolomitic. To this division, which extends over wide areas, the name of the Madison sandstone is given. Above this occurs the main body of the Lower Magnesian limestone, from eighty to 120 feet in thickness, including, at its base, a persistent stratum of oölitic silicious rock, and layers of green-sand, and consisting above chiefly of cherty dolomite. This, which is sometimes geodiferous, contains small quantities of lead ore, and very few organic remains.

The glauconite or green-sand from these ancient rocks closely resembles that from the cretaceous strata of New Jersey. An analysis, by the writer, of a specimen collected by Professor Hall at Red Bird in Minnesota, gave silica, 44.58; protoxyd of iron, 20.61; magnesia, 1.27; lime, 2.49; alumina, 11.45; potash, 6.96; soda, 0.98; water, 9.66 = 100.00. (Report of Geological Survey of Canada, 1863-66, page 232.)

§ 275. The Lower Magnesian limestone is directly overlaid

by the St. Peter's sandstone of Owen. This is a white, yellowish, or reddish friable sandstone, which attains a thickness of 120 feet in the southern part of the state, but elsewhere thins out and disappears. It has yielded no organic remains, except fucoidal markings, and is directly overlaid by the Trenton limestone group.

This is by Hall divided into three parts, a lower division of buff-colored dolomite, about twenty feet in thickness, holding the fossils of the Birdseye and Black River limestones of New York; a middle part, of about 100 feet of blue limestone, carrying the organic remains of the Trenton proper; and an upper part, the Galena limestone—the Upper Magnesian limestone of Owen—a porous dolomite, abounding in lead ore, and attaining a thickness of 250 feet. Above this are from 200 to 400 feet of thin-bedded limestones, shales, and clays, the representatives of the Utica and Loraine shales of the east, designated in the west the Cincinnati group.

§ 276. The most significant fact about the St. Peter's sandstone is that, according to Hall, it is clearly separated alike from the formations below and above, the transition at both horizons being "abrupt and without alternation or admixture of material." Irving has further noticed that it fills up eroded hollows in the Lower Magnesian limestone, (which is regarded as the representative of the Calciferous sandrock,) being abruptly succeeded by the limestones of the Trenton group. The St. Peter's sandstone thus occupies the position of the Chazy formation, which, as has been already set forth, (§ 242, 243,) shows in the eastern region a break both paleontological and stratigraphical, alike at its base and its summit, and in the Ottawa basin is in part a detrital rock. This intermediate sandstone in Wisconsin was consequently designated by Hall as the Chazy sandstone, (Geol. of Wisconsin, 1862; Irving, Amer. Jour. Science, [3] vol. IX, page 440.)

§ 277. It was in the lower sandstones of Wisconsin, Minnesota, and Iowa, that D. D. Owen discovered the remarkable trilobitic fauna, associated with numerous brachiopods and with fragments of crinoidal stems, which was described

by him in 1852. Hall, who reëxamined the strata and revised the fauna in 1862, distinguished three paleontological stages. Of these, the lower affords only *Conocoryphe*, with *Theca* and some linguloid shells. The middle stage contains *Arionellus*, *Agnostus*, *Ptychaspis*, certain species of *Dikellocephalus*, and of *Conocoryphe*, to which Hall referred some forms hitherto included in the preceding genus. With this middle stage is also found a graptolite, *Dendrograptus Hallianus*. The third or upper stage, declared by Hall to be clearly separated from the last, and from 400 to 500 feet above the lower stage, affords no species of *Conocoryphe*, but is marked by the large and characteristic species of *Dikellocephalus*, *D. Minnesotensis*, and *D. Pepinensis*, described as passing up into the Lower Magnesian limestone, (16th Appendix to Regents' Report, 1863, pages 120, 183.) This third stage is believed by Irving to correspond to the Mendota limestone.

§ 278. This series of about 1,000 feet of sedimentary strata below the St. Peter's or Chazy sandstone of Wisconsin, is thus shown by the studies of Hall, to include in its several faunas representatives of genera of trilobites found in both the Lower and Upper Cambrian of Great Britain, and in those sub-divisions of the Hudson-River group or Upper Taconic to which the names of Lower Potsdam and Levis have been given. The corresponding series of strata, consisting of alternations of sandstone and magnesian limestone, attains a still greater thickness in Missouri. The Artesian well at St. Louis passed through 2,489 feet of such strata between the base of the Trenton and the floor of crystalline granitoid rocks beneath. That the typical Potsdam sandstone of northern New York and central Canada, with its few organic remains, is represented somewhere in the western series, cannot be doubted, but until its fauna is better known, it will not be possible to fix its precise horizon. It will probably be found desirable, on further study, to revise the nomenclature of these lowest paleozoic rocks in America, and to establish new sub-divisions, as in Europe.

§ 279. In conformity with the general principle regulating

the distribution of sediments over the great American paleozoic basin, we find little or nothing in the silicious and dolomitic Cambrian strata of the Mississippi valley resembling the Upper Taconic conglomerates, sandstones and argillites of the eastern border of the basin. It is proper, in this connection, to call attention to some important points in the history of these latter rocks, and their relation to the Siluro-Cambrian strata, which have been omitted in the preceding chapters, though referred to in a foot-note on page 127.

§ 280. In the first annual report on the geology of the central district of New York, the strata above the Calciferous sandrock were described by Conrad as consisting of the fossiliferous limestones of Trenton Falls, overlaid by dark shales, to which succeed a series of fossiliferous lead-colored shales, alternating with gray sandstones, well displayed at and near Pulaski, on the Salmon River, in Oswego county. At the summit of these was a bed of sandstone quarried for grindstones, and in Oneida county the series was overlaid by a quartzose conglomerate. Vanuxem, who succeeded Conrad in the examination of the district the next year, gave to the Salmon River strata the name of the Pulaski shales and sandstones. These correspond to the Loraine shales, (named from Loraine, in Jefferson county,) and the Gray sandstone of Emmons, which were then supposed by the latter to be the equivalents of the Argillite and Graywacke series described by Mather, in his fourth annual report on the southern district of New York, by the names of the Hudson slate group, or the Hudson River slates, (§ 62, 64.) The counties of Jefferson and Lewis, in the northern district examined by Emmons, were connected with the Hudson valley through the central district, which embraced the counties of Oswego, Oneida, Herkimer, and Montgomery, extending southeastward along the Mohawk valley.

§ 281. The rocks of this district were now described by Vanuxem, under the name of the Hudson-River group, and according to him, included two entirely distinct divisions, the upper a highly fossiliferous series, the Pulaski shales and sandstones, found west of the Adirondacks in Jefferson,

Lewis and Oswego counties, and disappearing to the southeastward in Oneida county. These are the lead-colored shales and sandstones of Conrad. The lower member of the Hudson River group, as defined by Vanuxem, was named the Frankfort division, from Frankfort, in Herkimer county, and was described as consisting of greenish argillites and sandstones, which underlie the Pulaski shales to the northwest, as far as Jefferson county, constitute in Herkimer and Montgomery the only representative of the Hudson-River group, and extend eastward, through Schenectady, Albany, and Saratoga counties, to the Hudson river. This lower division was said to yield none of the organic remains of the Pulaski division, but to include some graptolitic shales. To the Frankfort slates and sandstones, it was suggested by Vanuxem, might belong the thick masses of argillaceous strata of "controverted age," (the Taconic of Emmons) along the Hudson valley.

§ 282. Vanuxem, while he thus attempted to connect the argillaceous strata of the northwestern counties with those of the Hudson valley, spoke of "the difficulty of separating or distinguishing the slaty or schistose members of the (Hudson River) group from those of greater age, with which on their eastern border the two (*sic*) are, more or less, really or apparently blended." The force of this observation is more clearly apparent to-day, when it is known that the larger part of these schistose rocks of the Hudson River valley are of much greater antiquity than the Pulaski, (Loraine) and Utica slates, and must be assigned a position below instead of above the Trenton limestones.

Vanuxem further remarks, that the two divisions of the Hudson River group, as defined by him, exist separately in Pennsylvania. The Pulaski slates, having in all respects, the same characters as in New York, are declared to occur in the Nippenose valley, west of the Susquehanna, while the Frankfort slates and sandstones appear to the east of the North Mountain, in the Kittatinny valley, and include the roofing-slates of the Delaware. These latter are placed by Emmons at the summit of the Lower Taconic, but were by Rogers included, with the fossiliferous shales of Nippe-

nose and Kishacoquillas valleys, in the upper portion of his Matinal division.

§ 283. It is important to note in this place, that, according to Vanuxem, the Oneida conglomerate, the admitted representative of the conglomerate and sandstone of the North Mountain in Pennsylvania, rests in Oneida county, New York, upon the Pulaski shales, (sometimes with the intervention of the Gray band, which was by Emmons united with the Oneida,) while in Herkimer county this conglomerate overlies directly the Frankfort shales and sandstones.

§ 284. In connection with the disappearance of the Pulaski or Loraine shales to the southeastward in the Mohawk valley, we may note the similar disappearance of the Trenton limestones. These, in Canada, have been found at points as widely remote as Quebec, Montreal, Ottawa, the Bay of Quinté, Lake Simcoe, and the shores of Lake Huron, to have a thickness of from 600 to 750 feet, being everywhere followed by the Utica slates and Loraine shales, with a united volume of from 800 to 1,100 feet or more. The thickness of the Trenton limestones in the northern part of Lewis county, New York, is, however, but 300 feet. This is reduced to 100 feet at Trenton Falls, and to thirty feet in the Mohawk valley, while south of the Mohawk the limestone is seldom over ten feet, and, according to Conrad, thins out and wholly disappears to the southeast. He also notes that the gray sparry fossiliferous beds, which, in Oneida county, he distinguished as a separate and lower division of the Trenton group, grow thin, and disappear to the eastward along the line of the canal, in Montgomery county.

For the statements in the preceeding sections, beginning with § 280, see the Geology of the Third District of New York, and also the previous annual reports of Conrad and Vanuxem on the district, *passim*. The facts should be considered in connection with the statements in § 245 with regard to the relations of the Trenton and its overlying argillaceous strata to inferior rocks, with those of Emmons in § 97, 98, and with the earlier statements of Eaton, cited in § 56. We shall return to the consideration of the questions here raised in a subsequent chapter.

CHAPTER V.

HISTORICAL SKETCH CONTINUED.

§ 284. We have in chapters II and III discussed the history of the crystalline stratified rocks of eastern North America, up to the year 1855, at which date the names of Laurentian and Huronian had already been applied to two divisions of these rocks (§ 144), which had been described and defined by the geological survey of Canada as more ancient than the base of the New York paleozoic series. The officers of that survey had then adopted, so far as regards the crystalline strata of the Atlantic belt (with the exception of the Laurentian) the view held by Mather, that these rocks were the altered equivalents of the Champlain division of that series, and consequently more recent than the Laurentian or the Huronian (§ 166–174). We shall now proceed to discuss successively the progress since made in our knowledge of the Laurentian and its divisions, of the newer crystalline schists of the Atlantic belt, and of the Volcanic formations around Lake Superior (§ 137).

§ 285. The so-called Metamorphic gneissic series to which, in 1854, the name of Laurentian was given had, as already shown, been by Logan, from his observations on the Ottawa river in 1845, divided into two groups, the upper one, with its intercalated bands of crystalline limestone, being regarded as a separate overlying formation ; (§ 133) a distinction which is well founded, but has generally been disregarded in subsequent descriptions of these rocks. In 1847 the present writer spent some time in the examination of the crystalline limestones of this series, and their associated rocks, as seen at various localities along the valley of the Ottawa, as far as Portage du Fort, and in the vicinity of Perth, Ontario. The observations then made were given in the report of the survey of 1847, (pages 125–138) and the results of chemical analyses of the materials collected at that time, in the report of 1850 (pages 35–46).

§ 286. In 1850, Mr. Alexander Murray, in company with the writer, examined these same rocks to the north of the Thousand Islands. The observations then made will be found in Murray's report of 1851 (pages 59–64). The most important fact there announced was the occurrence of a bed of silicious conglomerate, found in the township of Bastard, intercalated in the crystalline limestones of the series, which here dip N. 55° E. $< 30°$. The limestone layers, both above and below, are white, coarsely crystalline, graphitic and micaceous, while the overlying one contains chondrodite. The included conglomerate layer, eighteen inches in thickness, is a finely granular sandstone, including large and small well-defined pebbles of vitreous quartz, and others which could only be described as a laminated sandstone. Pebbles and rounded grains of feldspar, together with scales of mica and of graphite were also found in the matrix. It is not improbable that this unique occurrence may be due to a dislocation, followed by movements of the strata, by which a more recent conglomerate has become enclosed in the ancient limestones.

§ 287. It was not until 1853 and 1854, that the difficult task of unraveling the structure of these ancient rocks was undertaken by Logan. The first results of his labors

therein were set forth in the little essay called an *Esquisse Géologique du Canada*, published at Paris in 1855 (§ 144), but further researches were made by him in 1856, and his conclusions are given with some detail in the report for 1853–56, (pages 7-52) published in 1857;—which was accompanied by a map showing the geographical distribution of the Laurentian limestones in the counties of Argenteuil and Terrebonne, a little north and west of Montreal. In this report was shown the existence of one or more great bands of crystalline limestone, interstratified with the gneisses and accompanied by considerable masses of quartzite and of magnetite, the whole being greatly folded, and intersected by numerous masses of eruptive rocks.

§ 288. The rock already recognized by Emmons under the name of hypersthene-rock or labradorite-rock, in the Adirondacks (§ 88) was also found in the region in question. Rolled masses of it had long been known in the valley of the St. Lawrence, and the rock had been observed in place by Dr. Bigsby, on the northeast shore of Lake Huron, where it was described as occupying a breadth of five miles. (Amer. Jour. Science, I, viii, 66). In 1852 Logan found a considerable area of the rock in Mille-Isles, Morin and Abercrombie, in the county of Terrebonne, and a specimen of it was described by the writer in some detail, with analyses, in the report for 1852, (page 167) and shown to consist of cleavable lavender-blue labradorite, in a greenish base composed chiefly of the same feldspar with 4.8 per cent. of carbonate of lime and a little magnetite.

§ 289. In the following year the writer examined the rocks of this region in company with Logan, and subsequently extended his observations to several other points. The first results of these examinations are given in Logan's report for 1853–56 (pages 35–37,) and inasmuch as the rocks in question have since assumed a considerable geological importance it is thought best to reprint therefrom the following extracts, defining their lithological characters. (§ 132.)

§ 290. The rocks are described in general terms as "chiefly composed of lime-feldspar, varying in composition between labradorite and andesine, and are marked by the presence

of hypersthene and ilmenite." Of one locality adjoining the crystalline limestone in Mille-Isles it was said, "the rock is chiefly labradorite, and consists of a fine-grained paste of this mineral, of a purplish-grey, weathering to an opaque white, and holding cleavable forms of a lavender-blue feldspar, several inches in diameter. Many of these exhibit a fine golden-green and deep blue opalescence, and the same hues occasionally emanate from minute points in the paste. The rock is generally massive, and it is occasionally very difficult to find any indication of those parallel planes which are so generally present in common gneiss. The large cleavable forms of labradorite, however, as well as the hypersthene and ilmenite, are found to prevail in belts that appear to be parallel to one another, and garnetiferous or micaceous bands occasionally indicate the same arrangement."

§ 291. At St. Jerome, on the east side of Riviére du Nord, a rock belonging to the same area as that last mentioned was described as gneissic in structure. "Darker and lighter bands run parallel to one another, the shades being occasioned by the greater or less abundance of a fine-grained greenish lime-feldspar, weathering opaque white, which occurs in spots, surrounded by a darker colored network, consisting of a dark green pyroxene and magnetic iron ore, with small disseminated clusters of yellowish-red garnets. In this mass, large and small individuals of labradorite, some of them two or three inches in diameter, are irregularly disseminated, and irregular veins or apparent segregations occur here and there, composed of flesh-red orthoclase and translucent colorless quartz."

§ 292. "On the west side of the river, rock of a similar character is met with, but there is seen also an interstratified mass of reddish hornblendic gneiss, the feldspar of which is orthoclase. The breadth of the mass of gneiss is two hundred yards, and it is marked by beds darker than other parts from the presence of hornblende. * * On the west side of this mass of gneiss smaller bands of a similar nature seemed to alternate with those containing lime-feldspar. Beds of quartz were also interstratified, and some of these were in one place so loaded with small garnets as to

form a fine granular garnet-rock. * * Lime-feldspar rock, more resembling that of Morin in its opaque white massive aspect, was met with at New Glasgow, on the Achigan, in Terrebonne seigniory; the stratification, however, was well marked by bands of garnets and pyroxene, and by alternations of the rock, on the west side, with common gneiss." Similar rocks, belonging to the same area, were examined further to the northeast in Rawdon, and in Chertsey, in the county of Leinster.

§ 293. The materials collected in the localities above mentioned, and also in another area, in Château Richer in the county of Montmorenci, were subsequently submitted to a chemical and lithological examination by the writer, and described in the report for 1853–56 (pages 373–383) as belonging to crystalline strata closely associated with the limestones, gneisses and quartzites of the Laurentian series. Of the rocks in question it was said: "They are composed chiefly of feldspar, with small portions of black mica, green pyroxene, and occasionally epidote, garnet and quartz; portions of hypersthene are also frequently present, and hence the New York geologists have designated these essentially feldspathic strata by the name of hypersthene-rock. In addition to the minerals just mentioned, we may add ilmenite or titaniferous iron, which occurs sometimes in large masses, and at other times in small disseminated grains, which, like the hypersthene, appear to mark the planes of stratification. If to these we add small portions of iron pyrites, and a little disseminated carbonate of lime, we shall have the mineralogy of these rocks, so far as yet known."

"The texture of these feldspar rocks is varied; sometimes the mass is a confusedly crystalline aggregate, exhibiting cleavage-surfaces three or four inches in diameter, with a fine grained somewhat calcareous paste in the interstices. Sometimes the whole rock is uniformly granular, while more frequently a granular base holds, at intervals, cleavable masses of feldspar, often several inches in diameter. The colors of these rocks vary from grayish and bluish-white, to lavender and violet-blue; flesh-red, greenish and brownish tints are also met with; the colors are rarely brilliant.

These feldspars seldom occur in distinct crystals, but their cleavage is triclinic, a fact which taken in connection with the densities, varying from 2.66 to 2.73, shows them to belong to the group of which albite and anorthite may be taken as the representatives. The bluish cleavable varieties often exhibit the opalescence of labradorite, to which species American mineralogists have hitherto referred them; but with the exception of a few analyses by myself, we have had as yet no published chemical examinations of any of these feldspars. My investigations show that while all of them are feldspars with a base of lime and soda, the composition varies very much, being sometimes that of labradorite, andesine, or intermediate varieties, and at other times approaching to that of anorthite."

§ 294. Of the lime-feldspar rocks of the county of Leinster it was then said: "In the townships of Rawdon and Chertsey, they are often fine-grained and homogeneous, and constitute an exceedingly tough rock, with an uneven subconchoidal fracture, and a feebly vitreous lustre; this variety is bluish or grayish-white in color, somewhat translucent, and exhibits here and there the cleavage of grains of feldspar. Great masses of this rock are almost free from foreign minerals, while other portions abound in a green granular pyroxene, arranged in thin, interrupted parallel layers, with ilmenite. These layers of pyroxene are seldom more than four or five lines in thickness, and occur an inch or two apart, while the layers of the ilmenite are still thinner, and often enclosed in those of the pyroxene, along the limits of which deep-red grains of garnet are occasionally seen. These different minerals appear in relief on the white weathered surface of the rock, and give a picture of its stratified structure, which however is not less apparent on the surfaces of recent fracture. Small rounded bluish masses of cleavable feldspar are frequently disseminated in the same planes as the other minerals. In some instances the pyroxene appears to graduate into, and to be replaced by, foliated hypersthene."

§ 295. Of the lime-feldspar rocks of Château Richer, it was said: "They cover a breadth of two or three miles across

the strike, bounded by crystalline limestone on one side, and a quartzo-feldspathic rock on the other, and rising into small hills. In this area there occur several varieties of the rock, but the most interesting is the one made up of a fine granular base, greenish or grayish-white in color, holding masses of a reddish cleavable feldspar, which are sometimes from one tenth to one half an inch in diameter, but often take the form of large imperfect crystals, frequently twelve inches long and four or five inches wide. These dimensions correspond to the faces M and T, while the face P, characterized by its perfect cleavage, is from half an inch to two inches broad. Twin crystals sometimes occur, having a composition parallel to M."

"Hypersthene is met with throughout the rock in flattened masses, which, although variable and irregular in their distribution, exhibit a general parallelism; they are occasionally four or five inches in breadth, by an inch or more in thickness, and are separated from the granular feldspathic base by a thin film of brownish-black mica. Titaniferous iron ore is also found in the rock in grains and lenticular masses, occasionally an inch or two in thickness; these occur in the granular base, and generally near the hypersthene, but grains of the ore are occasionally found in the crystalline feldspar, [which is andesine]. Quartz, in small grains, is imbedded in the titaniferous iron ore, but was not observed elsewhere in the rock."

§ 296. The report already cited gave fourteen analyses of of these feldspathic rocks, including both the cleavable feldspars and the surrounding paste, and showing a variation in the amount of silica from 47.40 to 59.80 per cent., and in the lime from 7.73 to 14.24 per cent., the proportion of alkali (chiefly soda) generally decreasing as that of the lime augmented; while the specific gravity varied from 2.67 to 2.73. The analyses of all these feldspars, as well of the accompanying hypersthene and ilmenite, will be found under their respective heads in the Geology of Canada, where, on page 590, is given the mean composition of the feldspars, as deduced from many analyses. For the views at that time put forth as to the constitution of these feld-

spars, the reader is referred to the author's paper in the L. E. and D. Philosophical Magazine for May, 1855, and to his Chemical and Geological Essays, page 443.

§ 297. The report of the survey for 1858 (published in 1859) contains the results of further explorations by Sir William Logan, and his assistant Mr. James Lowe, in the Laurentian region already referred to, northwest of Montreal, during the years 1857 and 1858. An attempt was therein made to fix the succession and thickness of the gneissic and limestone series, and the conclusions then announced were confirmed by the labors of the following three years. The "Geology of Canada," a volume of 983 pages octavo, published in 1863, was in great part printed in 1862, and the first twenty chapters represented the state of our knowledge of the rocks in question at the close of 1861. Chapter XXII however gave the further results of the field-work of 1862. This volume was accompanied by an Atlas with explanatory text, which contained a colored geological map, showing the distribution of the Laurentian limestones in the counties of Ottawa, Terrebonne, Argenteuil and Two-Mountains. The breadth of the region thus mapped (on a scale of seven miles to the inch) was about fifty miles from east to west, and its greatest length about the same. The sharply folded, and often inverted strata have a strike about ten degrees east of north.

§ 298. The succession in this region, as now described by Logan, was as follows in ascending order from a great underlying mass of gneiss, which makes the Trembling Mountain in Grandison, and is designated in the geological map already referred to as

A. First Orthoclase Gneiss; thickness unknown.

B. First or Trembling-Lake Limestone band. . . . 1,500 feet.

C. Second Orthoclase Gneiss . . . . . 4,000 feet.

D. Second or Green-Lake Limestone band, including two subordinate bands of garnetiferous quartzite and hornblendic gneiss, making up about one half the volume . . . . . 2,500 feet.

E. Third Orthoclase Gneiss—including several bands of garnetiferous gneiss and quartzite in the lower, and much coarsely porphyritic gneiss in the upper part	3,500 feet.
F. Third or Grenville Limestone band, said to vary in thickness from 60 to 1,500 feet, having in some parts an interstratified band of gneiss, and estimated at	750 feet.
G. Fourth Orthoclase Gneiss including, besides a thin bed of limestone, a band of 600 feet of quartzite	5,000 feet.
	17,250 feet.

§ 299. The collective name of the Grenville series was subsequently applied to the whole succession from the base of the limestone B. to the summit of the gneiss G. (Geology of Canada, page 839). This corresponds to the upper group in the Laurentian series, originally indicated by Logan in 1845, (§ 133) while the great underlying mass of granitoid gneiss, A., of unknown thickness, which is largely developed in the county of Ottawa, and may be called the Ottawa Gneiss, is the lower group.

§ 300. The name of orthoclase-gneiss was used to designate the feldspathic rocks of the Ottawa and Grenville divisions, because the feldspar belongs chiefly to the species orthoclase, although, as was then pointed out: "Small portions of a white triclinic feldspar, which is apparently oligoclase or albite, are occasionally found with the reddish orthoclase of the coarser gneiss." It was further shown, however, that a fine-grained reddish gneiss from Grenville, in which orthoclase was apparently the predominant mineral, contained nearly as much soda as potash (Ibid, 587).

To distinguish from these quartzo-feldspathic rocks the more basic gneissoid rocks, consisting chiefly of lime-feldspars anorthic in crystallization, (for which Delesse had proposed the general term of anorthose) the name of anorthosite rocks, or anortholites, was at this time suggested for the latter.

§ 301. It was then the opinion of the present writer, as ex-

pressed in 1861, that "future investigations may furnish evidence which will divide the Laurentian series into several formations, distinguished by want of conformity and by mineralogical differences." (Ibid, page 586). This expectation was soon fulfilled. In chapter III of the Geology, from which the above section is condensed, a fourth limestone band, that of Morin, is mentioned as probably occupying a position above the fourth gneiss, G., and as followed by the great mass of anorthosite rocks which, with a generally high westward dip, occupy an area at least twelve miles in breadth, to the north and east of the region mapped. To these rocks was provisionally assigned a volume of 10,000 feet, but it was expressly said that "the thickness is wholly conjectural."

§ 302. The explorations of 1862 added materially to our knowledge of the relations of these anorthosite rocks. Lying apart, and to the west of the great area in the counties of Terrebonne and Leinster, there was discovered in Salaberry, a smaller portion of anortholite, beneath which one of the limestone bands of the Grenville series appeared to pass. It was also found that the Morin limestone band, (supposed to be a repetition of one of those named in the section) disappears in like manner beneath the southwest edge of the great anortholite area. From these facts it was considered "probable that the anorthosite rock overlies the whole Grenville series unconformably, and that the mass of it on the west side of Salaberry is an outlying portion," giving reason to suppose "the existence in the Laurentian system of two immense sedimentary formations, the one superimposed unconformably upon the other, with probably a great difference in time between them." In confirmation of what had been previously asserted as to its lithological character, it was further said: "This new formation, although characterized by a predominance of anortholites, appear to contain in some parts interstratified beds of orthoclase-gneiss, quartzites and limestones, all of which are found associated with it near New Glasgow" (Ibid, page 839).

§ 303. In the original description, the Fourth Orthoclase Gneiss, G. of the section, was said to be interstratified in

its upper part with anortholites (§ 292) and was regarded as showing a passage from the gneisses below into the anortholites above. Since however this upper series elsewhere includes layers of orthoclase-gneiss and quartzite, not unlike those found in the Grenville series, it is probable that these supposed beds of passage are really a portion of the newer formation.

It was both on account of this association, and of the gneiss-like structure of the anortholites themselves, that this overlying series was designated, alike in the text of the Atlas, and on the map published in 1865, by the name of Anorthosite Gneiss. This was then called Upper Laurentian or Labradorian, the name of Lower Laurentian being reserved for the gneisses, quartzites, and limestones of the Grenville series, and the underlying Ottawa Gneiss.

§ 304. The further history of these labradorite or anorthosite rocks may here be told. Besides the localities already mentioned, near Montreal and near Quebec, they are found at many places within the Laurentian region on the north side of the lower St. Lawrence. They are known in the parish of St. Urbain, near Bay St. Paul, and over a large area on the Saguenay, between Chicoutimi and Lake St. John. A description of the labradorite rocks of this latter district, as observed and collected by Mr. James Richardson in 1857, will be found in the report for that year (pages 79—84.) Many beautiful varieties are there met with, and the stratification, which is well marked, sometimes shows included bands of orthoclase gneiss, and in one locality a layer of pale green pyrallolite (renssellaerite.) In some instances the blue granitoid labradorite rock contains distinct grains of vitreous quartz, which is however comparatively rare. Similar rocks are found at many points along the north-west shore of the Gulf of St. Lawrence, from the Saguenay as far as Labrador. They are well seen at the mouth of the Pentecost river, about 160 miles below the mouth of the Saguenay, and on the Bay of Seven Islands, some forty miles further. This locality is probably connected with the large extent of similar rocks, observed by Prof. Hind to form a chain of

hills along the River Moisie. Labradorite rocks were also observed by Bayfield to occupy the coast for several miles, near Mingan. In each of these localities, these rocks appear to be in contact only with the Laurentian gneiss, except in the area near Montreal, where their southern border is unconformably overlaid by the Potsdam sandstone of the St. Lawrence valley.

§ 305. The rocks are widely spread on the coast of Labrador, where their characteristic feldspar was first found, and whence it takes its name. Prof. A. S. Packard, Jr., has described some of the localities in this region, where he found considerable areas of anortholite surrounded by gneiss, and observed bosses or domes of it resting upon stratified quartzose, hornblendic and feldspathic rocks, in such a manner as to lead him to suppose the anortholites to be eruptive, (Mem. Bost. Soc. Nat. Hist. Vol. I, part ii, pp. 214–217.) Labradorite rocks were long since observed by Jukes in the western part of Newfoundland, and Mr. Alex. Murray, in his geological map of the island, published in 1876, has shown, besides several smaller areas, a belt of more than fifty miles in length of these rocks, called by him Upper Laurentian, near St. George's Bay.

§ 306. The localities of labradorite rocks on the coast between the Saguenay and the Bay of Seven Islands, were examined by Mr. James Richardson in 1869, and the materials having been submitted to the examination of the writer, the results are set forth in Mr. Richardson's report for that year (Report of Progress for 1866–1869, page 305). The Laurentian there consists of coarser and finer reddish and grayish gneisses, often enclosing hornblendic and micaceous layers, and including great masses of vitreous quartz, sometimes pure, and at other times holding sparingly disseminated plates of flesh-red feldspar. Beds of crystalline limestone, enclosing green pyroxene, are included in the gneiss.

§ 307. The labradorite rocks there met with present many varieties resembling those found near Montreal. Besides hypersthene, they sometimes include nodular masses of red garnet, and others of a gray fibrous hornblende. Bands

of anortholites, coarser and finer in texture, and marked by these different minerals, serve to make very apparent the stratification, which is extremely regular, and near Pentecost River is seen in a range of low cliffs, dipping N. 23° E. < 30° to 40°. At the Bay of Seven Islands, in like manner, the dark bluish anortholites, characterized by hypersthene, and including great masses of titanic iron-ore, appear for a distance of three or four miles, with a nearly uniform dip of from 10° to 20° to the northward. The reddish Laurentian gneiss is in one place "seen to be distinctly overlaid by a patch, only a few yards square, of labradorite rock, showing considerable varieties in character, and clearly stratified."

§ 308. The conclusion from all the observations along this coast is thus stated: For the Laurentian gneiss, "the strike is generally nearly north and south, with dips often approaching the vertical. The strata are all more or less broken, contorted and faulted. The labradorite rocks rest unconformably upon the Laurentian; they generally strike nearly east and west, at comparatively moderate angles, with little or no appearance of contortion or disturbance." Both the Laurentian and the labradorite rocks are cut by granitic veins containing red orthoclase, greenish oligoclase, black hornblende, muscovite, molybdenite, and sometimes crystalline masses of magnetite.

§ 309. At an early date in the history of the investigation of the Laurentian its mineralogical resemblances with the Primitive gneiss of Europe were evident. The writer, in 1854, declared that both "in position and in lithological characters the Laurentian series appears to correspond to the old gneiss formation of Lapland, Finland and Scandinavia," (Amer. Journal Science II. xviii, 195,) and in the *Esquisse Géologique*, already cited, it was added "to the similar rocks of the north [west] of Scotland." In the description then given, the anortholites were as yet regarded as forming a part of the Laurentian, and these rocks, as found in Essex county, New York, had, we have seen, been by Emmons compared with the hypersthene-rock or labradorite-rock found by Macculloch in the Western Islands of Scot-

land. In order to verify this comparison, the writer, having first procured specimens of the rock from Loch Scarvig in the Isle of Skye, obtained access to the collections made in that island by Macculloch, and now in the possession of the Geological Society of London, and convinced himself of their close resemblances to the anortholites of New York and Canada.

§ 310. Both Macculloch and Emmons regarded these labradorite rocks are eruptive. Giekie, in his subsequent geological studies in Skye, expressed the same view, and appeared to confound them with certain eruptive greenstones. The writer's observations and conclusions respecting these, and the other crystalline rocks of the Western Islands, were set forth in the Dublin Quarterly Journal for July, 1863, where the stratified character of the labradorite-rocks of Canada, and their correspondence with those of Skye was pointed out. In the following year Prof. Haughton, of Dublin, visited Loch Scarvig, in Skye, and in the same Journal for 1865 (page 65) describes the rock, which he submitted to analysis, as an aggregate of labradorite, often coarse grained, with pyroxene and titanic iron, and declared it to be evidently "a bedded metamorphic rock."

§ 311. Similar anorthosite-rocks were known to exist in the gneissic region of Norway, and had been by Esmark called norites, from the name of the country. A careful examination by the writer of a large collection of these, selected for ornamental purposes, and sent by the Royal University of Christiania to the Paris Exhibition of 1867, showed them to be precisely similar to the labradorite-rocks of North America. In a printed notice accompanying this collection it was stated that these various rocks, consisting of labradorite with hypersthene, diallage and bronzite, had, in the geological map of Southern Norway, published in 1866, been designated by the common name of gabbro. This notice at the same time suggested that "the name of norite should be preserved for certain varieties of gabbro rich in labradorite, which varieties may, in great part, with justice be called labradorite-rock, since labrador-feldspar is their predominant element."

§ 312. The geological map of Norway above referred to shows that these so-called gabbros occupy considerable areas within the Laurentian gneiss region of Norway, and are by the authors of the map, Kjerulf and Dahl, regarded as eruptive, though they are described by them as often presenting the characters of stratified rocks. In fact, the banded stratiform structure of these Norwegian norites is as clearly marked as that of any of those of North America, from which they cannot be distinguished. Of the above collection, the norites of Sogndal and Egersund presented fine varieties of grayish or brownish violet tints, while a dark violet norite comes from Krageroë, and also from Langoë and Gomoë, and a white granular variety from the Gulf of Laerdal, in the diocess of Bergen. Very beautiful varieties of coarsely granitoid violet-colored norite, often opalescent, are brought from Southern Russia, where the rock is said to form a mountain mass in the government of Kiew. For further details on the norites, both of Norway and North America, see the writer's essay On Norite Rock, read before the American Association for the Advancement of Science in 1869, and published in the American Journal of Science for November of that year.

§ 313. The prior name of norite was, in accordance with the suggestion of the Norwegian geologists, henceforth adopted for these rocks in America, and since it was apparent that they form a stratified series entirely distinct from the Laurentian, the writer, in his address before the Association just named, in 1871, substituted, in place of Upper Laurentian and Labradorian, the designation of the Norian series for these labradorite or anorthosite rocks. (See further his Chemical and Geological Essays, pages 279–281). Nothing more is known of the norites there mentioned as found in the vicinity of St. John, New Brunswick, where they occupy a small area in a greatly disturbed district; while the labradoritic rocks in the White Mountains, which had by Hitchcock been referred to norite, are now found by him to be eruptive masses. A few scattered erratic blocks of norite have been found on the New England coast, near the mouth of the St. Croix, and at Marblehead, Massachu-

setts, while the occurrence of similar masses in greater abundance in northern New Jersey, suggests the possible presence of the Norian series among the crystalline rocks of the Highlands.

§ 314. The presence of titanic iron, approaching menaccanite or ilmenite in composition, seems to be very characteristic of the Norian rocks. In Canada, at St. Urbain, at Lake St. John and in the Bay of Seven Islands, are found masses of this mineral so large as to attract attention as to a possible ore of iron (Geology of Canada, pages 501, 754, and report for 1866–69, pages 252, 260). Similar ores are found with the norites of Krageroë and Egersund in Norway, and the writer has found an iron-ore from Skye to be of the same species.

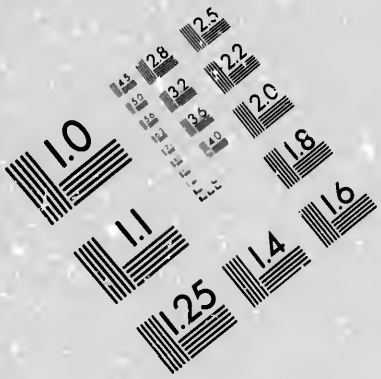
§ 315. A blue granitoid norite, and a titanic ore like those of Canada and Norway, are found associated in Wyoming, on the Laramie plains, near the Chugwater creek, and were identified and described from specimens, by the writer, in the Transactions of the American Institute of Mining Engineers, in 1873 (Vol. I, 335). Mr. Arnold Hague, in the Survey of the Fortieth Parallel (volume II, pages 13–16) has since described under the name of gabbro, this same norite, which, from its analysis, is shown to be a nearly pure labradorite, while the iron-ore holds about one fourth its weight of titanic oxyd. These, though by him regarded as eruptive, suggest the existence, in this region, of an area of stratified Norian rocks.

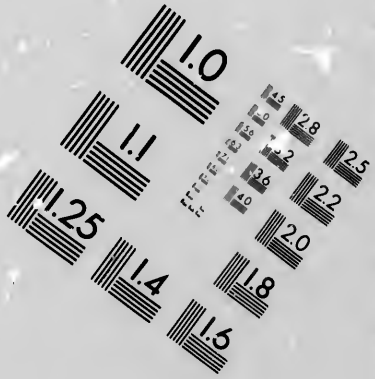
§ 316. Titanium is not unknown in the Laurentian and Huronian iron-ores, though seldom in such amounts as to be prejudicial to their use in metallurgy, but in all the cases with which the writer is acquainted, the iron-ores of the Norian are so highly charged with it as to be unfit for use in the blast-furnace. Having been called in 1870 to examine the large deposits of highly titaniferous ores near Westport in Essex county, New York, these were found to be included in the Norian rocks of that region, which offer a marked contrast to the Laurentian gneisses near by, in which are included the magnetic ores so extensively mined in the vicinity of Port Henry (Trans. Amer. Inst. of Mining Engineers, Vol. I, page 335).

§ 317. Prof. James Hall has since examined this region, and in a communication to the American Association for the Advancement of Science, in 1876, has confirmed the writer's observations. Hall distinguishes two parts in the crystalline rocks of Essex county, the lower consisting of coarse feldspathic and quartzose rocks (gneisses) often with black hornblende and with garnet, including great beds of magnetic iron-ore. These rocks are "succeeded by massive beds of labradorite-rocks. This part of the formation is marked by extensive beds of titaniferous iron-ore. The succession is however unconformable, and the interval between the two series of rocks is not determined" (American Journal of Science, III, xii, 299).

§ 318. The Norian region in Essex county, New York, rises into considerable hills, the highest, Mount Marcy, being 5,400 feet above the sea, and extends along the shore of Lake Champlain, from near Westport to Port Kent. The railway between these two points, in its course around Willsborough Bay, is cut for about five miles through the Norian rocks, which may, there be studied to great advantage. Prof. Albert R. Leeds, of Hoboken, New Jersey, has lately devoted much attention to these rocks in Essex county, and has embodied his observations in a paper read before the New York Academy of Science, December 11, 1876, and published under the title of "Notes on the Lithology of the Adirondacks," in the American Chemist for March 1877, which forms a very important contribution to the history of the Norian series. In this, besides giving an analysis of the previous observations of Emmons, and of the present writer, he has made careful chemical, mineralogical and microscopical studies of the Norian rocks collected by himself in Essex county.

§ 319. Rejecting the names of gabbro, hyperite, diorite and diabase, by which many would designate these rocks, he has called them all norites. Some of these are described as porphyritic from the presence of polysynthetic macles of smoky blue labradorite in a granular or crypto-crystalline matrix, which is often yellowish in color. In some cases this matrix or paste is almost entirely wanting, while in





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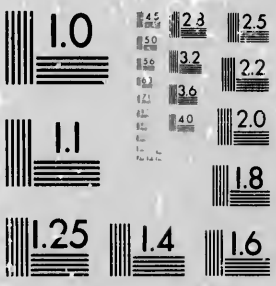

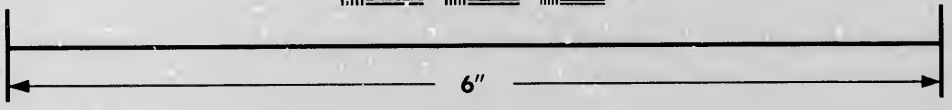

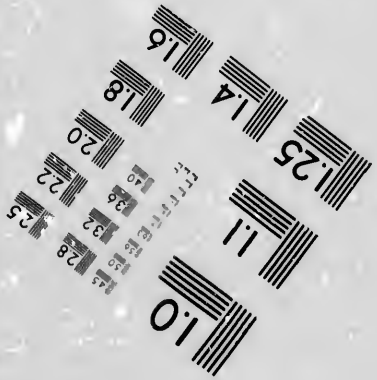

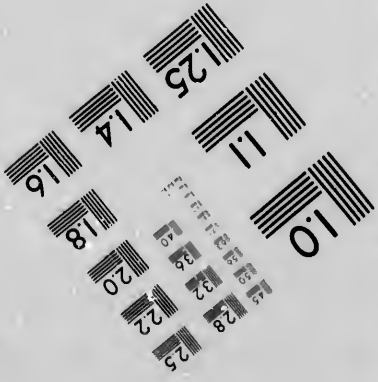

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others, from the absence of the crystals, we have a compact greenish feldspar-rock, with some admixed diallage and red garnet. This latter mineral is a common element in these rocks, and is generally associated with the non-feldspathic portion, garnet often bordering the masses of diallage. In some instances, by the disappearance of feldspar, and the predominance of garnet, with some hornblende, the rock passes into a grenatite. Other varieties are described as hypersthenic, hornblendic, and pyroxenic norites. There are also pyroxenites with but little admixture of feldspar, and the pyroxene is sometimes broadly foliated and diallagic, and at other times green and granular like coccolite. Quartz is generally present, but for the most part in minute particles only visible under the microscope. Titanic iron is always found in these rocks, sometimes with magnetite.

§ 319. Of two analyses by Prof. Leeds, one of the bluish feldspar from the hypersthenic granitoid norite which forms the summit of Mount Marcy, and the other from the yellowish crypto-crystalline paste of a porphyritic norite, both have very nearly the composition of a proper labradorite. He also analyzed the hypersthene and the diallage of these rocks. (A yellowish-green granular epidote has been found by the writer accompanying a white feldspar in one of the nearly compact norites from this region.) Prof. Leeds has also given the analysis of a reddish granular quartzo-feldspathic rock found among the norites, which contained admixtures of menacannite and magnetite, and yielded seventy-six per cent. of silica, over five per cent. of potash, and three of soda, with but traces of lime. From its chemical composition, and its microscopic characters, it would seem to represent one of the orthoclase rocks which have been described as occurring in the Norian series.

Prof. Leeds notes that these norites are evidently stratified, and are clearly to be distinguished from the eruptive doleritic rocks, also described by him, which traverse them. These dolerites have however the same constituent minerals, and, he suggests, may perhaps have been derived from deeply-seated portions of pyroxenic norites.

§ 320. The calcareous portions of the Laurentian series

are in part pure limestones, and in part either dolomites, or limestones more or less magnesian. They are themselves crystalline, and abound in crystalline species well known to mineralogists. The geognostical relations of these calcareous rocks offer many points of interest. We have seen that Maclure early recognized the fact that the crystalline limestones of his Primitive Gneiss formation were interstratified with the gneissic and granite-like rocks (§ 46). This view was also shared by Nuttall, but Emmons classed the crystalline limestones of northern New York among the unstratified rocks. Mather, while admitting the stratified character of some of them, conceived that certain limestones of the region just named were eruptive, and had been "injected in a fluid state." (§ 82–87.)

§ 321. The studies, by the writer, of the Laurentian limestones of Canada and New York, enabled him, in 1866, to explain these seeming contradictions by showing that besides the stratified limestones, which are clearly indigenous, and form contemporary portions of the Laurentian series, there are endogenous masses or concretionary veins of crystalline carbonate of lime, which traverse the gneissic rocks of the series and, containing the same mineral species as the bedded limestones, had hitherto been confounded with these.

§ 322. The history alike of the limestone beds and the calcareous vein-stones of the American Laurentian, including their mineralogy and lithology, as well as the history of similar crystalline limestones in various parts of Europe, is discussed in the report of the Geological Survey of Canada for 1863–66, pages 181–229.

Therein, on page 216, the deposits of franklinite and zincite, with willemite, found in Franklin and Sterling, New Jersey, were noticed, on the authority of H. D. Rogers, as occurring in veins, while at the same time a doubt was expressed "whether these ores do not, like the magnetites, occur in the stratified rocks of the region." The writer's subsequent studies in the localities mentioned have satisfied him that the ores in question are really indigenous interstratified masses.

The above essay was reprinted, with some additions, in the Report of the Regents of the University of New York for 1867, Appendix E, and a summary of its principal points will be found in Chemical and Geological Essays, pages 208–219.

§ 322. Masses of crystalline limestone containing such characteristic minerals as hornblende, pyroxene, serpentine, chondrodite, mica, apatite and graphite may belong either to beds or to veins, and in small outcrops it is sometimes difficult, if not impossible, to distinguish one from the other. The veins are often of large size, and not unfrequently contain larger or smaller masses of the wall-rock. Such an occurrence appears to have been noticed by Mather, who described a cliff of crystalline limestone, as having "a mass of stratified hornblendic gneiss distinctly imbedded in it." (§ 35). Similar cases are found in North Burgess, in the province of Ontario.

§ 323. A good example of this phenomenon is seen near the town of Port Henry, in Essex County, New York, in a quarry whence limestone has been got for the blast-furnaces. Here, irregular elongated angular fragments of dark hornblendic gneiss, from two inches to a foot in thickness, were found completely enveloped in crystalline carbonate of lime. In 1877, five such masses of gneiss were exposed in an area of a few square yards. One of these, a thin plate of the gneiss, having been broken in two, the enclosing calcareous matter filled the little crevice, keeping the fragments very nearly in their place. The carbonate of lime, which is coarsely granular, and contains some graphite and pyrite, is banded with lighter and darker shades of color, and one of its layers was marked by the presence of crystals of green pyroxene and of brown sphene.

The contact of this mass with the surrounding gneiss, which is near by, is concealed. No serpentine was found in this limestone, though it abounds in a limestone quarried in the vicinity. About half a mile to the north is still another quarry, opened in a great breadth of more finely granular and somewhat graphitic limestone, which, near its border, presents three beds of two or three feet each, inter-

stratified with the enclosing gneiss. The first-described locality seems clearly to be a brecciated calcareous vein enclosing fragments of the gneiss wall-rock.

§ 324. Prof. James Hall appears to have observed similar cases. In the paper quoted above (§ 317) he gives some account of the crystalline limestone, as seen in the vicinity of Port Henry, and says: "Sometimes it is conspicuously brecciated, and contains fragments of gneiss-rock, which seem to have been derived from the strata below, upon which the rock lies unconformably." He concludes that these crystalline limestones do not belong either to the Laurentian, or to the unconformably overlying labradorite (Norian) rocks, but to a newer formation. The inclusion of fragments of gneiss is however the only ground assigned in support of the view that these calcareous masses belong to an unconformably overlying formation, and the facts observed by the writer lead to the conclusion that the calcareous masses of the region, except so far as they form interstratified portions of the Laurentian or of the Norian series, are to be regarded as endogenous masses or veinstones—the eruptive limestones of Emmons and of Mather. The banded or stratiform arrangement shown in the distribution of the foreign minerals in some of these, is to be compared with the similar structure often observed in granitic and other concretionary veins. See for a discussion of this, Chemical and Geological Essays, pages 193, 198; and as regards the banded structure resulting from the flow of eruptive rocks, page 186.

§ 325. The indigenous crystalline limestones of the Norian, so far as known, resemble those of the Laurentian. The hypersthene rocks of New York, are, according to Emmons, intermixed and penetrated with a crystalline limestone containing the usual characteristic minerals, (§ 88) from which we may perhaps infer that the limestone-veins are common to the Norian and Laurentian series. The age of these veinstones is greater than that of the Lower Cambrian series, since the Potsdam sandstone in South Burgess, Ontario, has been seen to rest upon the eroded outcrop of

one of these veins, and to include rolled fragments of apatite, apparently derived from it.

§ 326. The finding of the organic form known as *Eozoon Canadense* marks an epoch in the history of the Laurentian series, and the history of its discovery has been well told by Dr. J. W. Dawson, in his excellent little volume on the subject, entitled The Dawn of Life (London, 1875). There are however two slight corrections to be made therein, the first of which regards the argument urged by the present writer in proof of the existence of organic life in the Laurentian age. This, on page 27 of the volume just cited, (and previously in the Quarterly Journal of the Geological Society, Vol. xxvi. page 113) is said to have been put forth in 1861, or three years after the discovery of the remains of Eozoon, when they were already supposed to be organic. In fact, the language there quoted from an article in the American Journal of Science of that date, was but a repetition of views put forward in the same journal for May, 1858, II, xxv. 426) where it was declared that a great mass of evidence "points to the existence of organic life even during the Laurentian or so-called Azoic period." See also Chemical and Geological Essays, pages 13 and 302.

§ 327. It was in the autumn of 1858 that Mr. John McMullen, then attached to the survey of Canada, and an intelligent and enthusiastic student of geology, who was familiar with the above views on this question, and fully appreciated the importance of such a discovery, found in the crystalline limestone at the Grand Calumet Falls, on the Ottawa, specimens of what he believed to be a fossil coral. These, he first of all submitted to the writer, who then compared them with Stromatopora, and laid them before the director of the survey. The appearance of these specimens at once recalled certain specimens similar in form, which had been collected in North Burgess by Dr. Wilson of Perth, Ontario, and by him presented to the museum of the geological survey, but had not hitherto been critically examined, nor suspected to be organic. The careful microscopic study of the specimens from these two localities, which were submitted to Dr. Dawson, failed to give any

satisfactory evidence of the true nature of these singular forms, which were however described as probably of organic origin, and figured in 1862, on page 49 of the Geology of Canada, (§ 297.)

§ 328. In 1863, some blocks of serpentinic limestone, procured by the geological survey, and destined for the marble-cutter, were observed by Logan to contain in abundance, forms apparently identical with those above noticed, but more perfectly preserved. These blocks had been got by Mr. James Lowe from a quarry in Côte St. Pierre, in the seignory of La Petite Nation, which lies on the north side of the Ottawa River, immediately to the west of Grenville. This limestone-quarry, according to Logan, is on the upper limestone band of the Grenville division of the Laurentian (§ 299). The precise horizon in the series of the specimens from the other localities named is not known.

Specimens from this new locality were at once placed in the hand of Dr. Dawson, who early in 1864 declared that they were the remains of a foraminiferal organism, to which he gave the name of *Eozoon Canadense*. The first announcement of this was made by the writer in the American Journal of Science for May, 1864, and in February, 1865 there appeared in the Quarterly Journal of the Geological Society of London, a description of Eozoon by Dr. Dawson, together with discussions of its geological and mineralogical relations by Logan and the present writer. For further details, and for the subsequent history of Eozoon, the reader is referred to Dr. Dawson's volume already quoted, and also to Chemical and Geological Essays, pages 303,–411.

§ 329. Within the limits of the region in Canada originally described as Laurentian, there are, besides the Laurentian and Norian series, other and more recent crystalline stratified rocks, which require description. An area of these has for many years been known in the county of Hastings, which extends northward from the eastern portion of Lake Ontario. The rocks in question were first noticed by Mr. Murray in his report for 1852 (pages 104–105) as "interesting diversities in the Laurentian series," seen in the towns of Madoc and Belmont. They were described

by him as consisting of fine grained silicious clay-slate, passing into micaceous and talcose slates, often calcareous and pyritiferous, and sometimes holding crystals of magnetite, associated with which were great beds of conglomerate, including pebbles of quartzite, with others of greenstone and of a reddish feldspathic rock. In addition to these, were beds of granular magnesian limestone, sometimes becoming schistose. These strata were said to have a moderate dip to the southeast, but their relation to the gneissic rocks of the surrounding region was not determined.

§ 330. The schistose rocks in the townships named, and in some others adjacent, were again examined in 1864, by Mr. Thomas Macfarlane, and noticed by him in the report for 1863–66 (pages 93–94). The argillaceous and micaceous slates, associated with conglomerates, were further described, and were said to graduate into the limestones of the series, of which two varieties were noted, the one distinctly crystalline, white or gray in color, often banded, sometimes micaceous, and quarried as a marble, the other finer grained, less crystalline, and of a dark gray color.

Macfarlane also noticed in Elzivir and Madoc considerable areas of another group of strata, distinct alike from the last and from the gneisses of the region, and consisting chiefly of pyroxenic and hornblendic rocks, the latter sometimes becoming micaceous. These were described as forming varieties of diabase and of diorite, and passing into diorite-slate and chlorite-slate. He also noticed the occurrence of a red petrosilex porphyry. The rocks of this group were found by him to include the magnetic iron-ores of Marmora and Seymour.

§ 331. Macfarlane was disposed, on lithological grounds, to regard these two groups of schistose rocks as belonging to a newer series than the surrounding Laurentian gneisses, and compared some of them to the Huronian, but Logan, in a foot-note to the report, on page 93, objected this view, and suggested that "the Hastings rocks may be a higher portion of the Lower Laurentian series than we have met elsewhere." He further remarked that while these rocks offer certain resemblances with the Huronian, and with the

crystalline rocks of the Green Mountain range in Canada, "the micaceous limestones of Hastings more closely resemble the micaceous limestones which run from Eastern Canada into Vermont, on the east side of the Green Mountains." These, however, it was argued by him, from the evidence of associated fossiliferous strata, are Devonian, while "the Hastings limestones, which are highly corrugated, are unconformably overlaid by horizontal beds of the Birdseye and Black-River limestones." He added in proof of their relations to the Laurentian, that these Hastings limestones hold *Eozoon Canadense.*

§ 332. Fragments of Eozoon had already been detected by Dawson in 1866, in a specimen of the limestone from Madoc, collected many years previously by Logan. In that same year Mr. Henry G. Vennor was sent to begin a detailed examination of the rocks of the "Hastings series," as it was then called, and, his attention having been called to this matter, he found in the township of Tudor, numerous specimens of the Eozoon "imbedded in an impure earthy dark gray limestone, with which, and with carbonaceous matter, the cavities of the white calcareous skeleton are filled;" unlike the greater number of the specimens from the Ottawa, which are filled by serpentine or by pyroxene. These specimens were examined, figured and described by Dawson, and an account of their geological relations, so far as then known, was given by Logan in the Journal of the Geological Society for August, 1867. He there expressed the opinion that "the Hastings series may be somewhat higher than that of Grenville."

§ 333. In the report for 1866–69 (page 144,) and in that for 1870, (page 310) Mr. Vennor gave the results of his observations in Hastings and some adjoining counties, during the four years, 1866–69, his materials having previously been submitted to the examination of the writer. The various crystalline rocks, with a northeast and southwest strike, come out from beneath the fossiliferous limestones of the Trenton group, which have here a gentle southward dip, and occupy the southern townships of Hastings county, besides forming some small outliers further north, in Elzivir, Mar-

mora and Madoc. These crystalline rocks were included in three groups, as follows, in ascending order:

I. A mass of reddish granitoid rock with obscure marks of stratification, followed by several thousand feet of gneisses with crystalline limestones and beds of magnetite. These rocks had all the characters of the Laurentian, to which they were referred.

II. A series of dioritic and diabasic rocks, massive and schistose, sometimes conglomerate, passing into chloritic schists, with beds of steatite, magnesian limestone, and petrosilex, and with magnetite and hematite ores. These rocks, having an estimated thickness of nearly 10,000 feet, were regarded as Huronian.

III. The series of bluish and grayish, occasionally glossy slates, quartzites, conglomerates, and limestones, already described in § 330, 331. The conglomerates include pebbles of quartzite, of greenstone, and of gneiss. The crystalline dolomites are near the base of the series, while the fine grained, grayish, more or less schistose and earthy limestones, containing Eozoon, form the upper 1,000 feet of the series, which has a probable thickness of about 3,800 feet.

§ 334. The provisional name of the Hastings series will be reserved for division III. The strata of both I and II are described as generally vertical or highly inclined. The strata of division III are arranged in several synclinals, with moderate dips, and rest unconformably both on the Laurentian and upon the Huronian series. The frequent absence of the latter at the base of the Hastings series, indicates the existence of two stratigraphical breaks in the succession of these crystalline strata. The rocks of divisions II and III are traced northeastwards, out of the county of Hastings, across that of Lenox and Addington, and of Frontenac, into Lanark and Renfrew, and nearly to the Ottawa river, a distance of about eighty miles along the strike.

§ 335. There appears however, to be still another group of crystalline rocks in the region under examination. The rocks of the Hastings series, in the township of Levant, are bounded to the west by an elevated ridge of the underlying red Laurentian gneiss, by which they are separated from

a series of mica-schists and gneisses. These extend northward through Levant, Palmerston, and Blythfield, where they are found dipping at low angles to the east and west, occasionally attaining 45°, and sometimes nearly horizontal. They consist of friable quartzose mica-schists, sometimes fine grained and ferruginous, but often made up in great part of large distinct laminae of silvery-white mica. With these are associated grayish-white fine-grained gneisses, black hornblendic beds, and small bands of granular limestone. These rocks were, in the report for 1870, (page 311) compared with the mica-schists and gneisses of the White Mountain series, and with similar rocks from about Lake Superior. At the same time, they were said to resemble some parts of the Hastings series, as seen in Madoc and Tudor.

§ 336. In the report for 1874 (page 124) Mr. Vennor has farther described this so-called Mica-Schist series, which is said to have a breadth of about one and a half miles in the first two townships mentioned above, and to have to the west of it a considerable area of the gray fine-grained and friable gneisses. From the relations of these to certain similar strata found farther to the southeast, Vennor concludes that these gneisses and mica-schists occupy a position above division II, and beneath the limestones of III. Their precise relations to these latter does not however appear. The mountain-belt of red granitoid gneiss, already described as separating these limestones and calcareous schists on the east from the Mica-Schist series on the west, has a uniform eastward dip, and seems to overlie the latter, an appearance supposed by Vennor to be due to an uplift of the older formation.

In the report last quoted there are also described, under separate heads, groups of granitoid and hornblendic rocks, which are probably to be regarded as portions of one or the other of the lower divisions.

§ 337. In the years from 1869 to 1874 Vennor was engaged in examining the distribution of the crystalline rocks to the southeastward of the belt above mentioned, across the counties of Lanark and Frontenac, as far as the western

border of the Ottawa paleozoic basin. In the report for the last mentioned year he has described the apparent succession of the Laurentian rocks, as deduced from many observations in the townships lying to the westward of the town of Perth. A section is given for a distance of about six and a half miles across the strike of the rocks, which have a constant dip to the southeast, varying from forty to eighty degrees. The transverse surface-measurements and the observed dips of each sub-division are given, but no attempt is made to estimate the vertical thickness of the several masses.

§ 338. Beginning at the west, we have, in ascending order, as follows:

1.	Red gneiss, with hornblendic strata (40°–60°) .	3500 feet.
2.	White highly crystalline limestone, with serpentine and graphite, and some interstratified hornblendic gneiss (40°–60°)	2600 "
3.	Hornblendic gneiss, passing into gneissoid and granitoid hornblendic diorites, with grains and layers of epidote, and small included bands of crystalline limestone (60°–80°)	5500 "
4.	Gneissoid rock consisting of white feldspar, hornblende and quartz (45°–80°)	1500 "
5.	White limestone, coarsely crystalline, with yellow mica and graphite, and included bands of orthoclase and quartz-rock (60°)	2600 "
6.	Red and dark-colored gneiss and hornblende-rock, with great beds of magnetite and small bands of crystalline limestone (45°–60°) . . .	7900 "
7.	White limestone, very coarsely crystalline, with disseminated chondrodite, mica and graphite, and including layers of quartzite and hornblendic gneiss (45°–80°)	2600 "
8.	Red granitic and hornblendic gneiss (45°–80°)	2600 "
9.	Crystalline limestone like 7, (60°–80°); from 60 to	100 "
10.	Red gneiss and hornblende rock, with beds of magnetite (80°)	1300 "
11.	Red gneiss with marked stratification, becoming fissile near the summit, where it holds beds of flesh-colored crystalline limestone with black spinel (40°–80°); 3000 to	5000 "

§ 339. In view of the persistent eastward dip of these rocks, and the great difficulty of distinguishing between different masses of similar gneisses and crystalline lime-

stones, it must remain a question whether the numbered sub-divisions of the above section are to be regarded as members of a consecutive series, or, in part, as repetitions, through sharp overturned folds, or through faults, as appears in the example mentioned in § 336, and is so generally the case in the strata of the Atlantic belt. In the case of the Ottawa section, (§ 298) Logan was enabled to establish a succession by showing the recurrence of the masses on the opposite sides of a synclinal, but in the present instance, the immediate superposition of the paleozoic strata, to the eastward, makes this method impossible.

§ 340. To the above series, with a breadth of 35,500 feet, succeeds, according to Vennor, another calcareous belt, not described, and above this what he regards as the highest member of the system, noticed in detail in the report for 1872–73 (page 162) as lying in shallow and frequently overturned synclinals. The rocks of this highest member are displayed along the Rideau canal, in North Burgess, North Crosby, Bedford, Loughborough and Storrington. Their vertical thickness, in different sections, was estimated at from 2600 to 3900 feet. They are described as reddish gneisses, in parts abounding in red garnet, and including two bands of crystalline limestone, with beds, both near the base and the summit of the series, characterized by a predominance of greenish pyroxene, and designated as granitoid pyroxenic gneisses, passing into a pyroxenic schist with garnets. Apatite is found, both disseminated and forming layers, alike in the limestone and the pyroxenic rocks, and also in short irregular veins cutting the strata.

The mineralogy and lithology of these rocks, was previously described at some length by the writer in the report of 1866–69 (pages 224–229) and the characters of the pyroxenic masses were noticed in the Geology of Canada (1863) page 475, where the associated feldspar is shown to be orthoclase, often with sphene and with quartz.

§ 341. The limestones of this upper member which, according to Vennor, are distinguished from those below them by the presence of apatite, contain the Eozoon found in North Burgess, and are conjectured, from their mineral

associations, to be the same with the upper limestone band of the Grenville series, which yields the Eozoon of Côte St. Pierre. In this series, according to Logan, there are but three great limestone bands which, with their associated gneisses, were described as constituting an "upper group" or system, overlying the "lower group" of granitic or syenitic gneisses without limestone, which we have called the Ottawa gneiss. Mr. Vennor, in a late note in the American Journal of Science, for October, 1877, appears to have overlooked this distinction, pointed out by Logan in 1847, and claims the merit of having distinguished between the "old fundamental red gneiss system" without limestones, and the great overlying series of gneisses with crystalline limestones, which he calls his "second system," and with the limestone bands of which, he asserts, are found all the economic minerals of the Laurentian. This was already pointed out by the writer in the report for 1863–66 (page 186) where, after designating these limestone bands of the Grenville series, with their "attendant pyroxenites, amphibolites, serpentines, magnetites, etc," as so many "limestone groups," it was said "the ores of iron, copper, nickel, and cobalt, the apatite, mica and plumbago, as well as the serpentines and the marbles of the great Lower Laurentian series, belong, so far as yet known, to the limestone groups." It will be remembered that the term Lower Laurentian, then used, included both the lower or Ottawa gneiss and the rocks of the Grenville series.

§ 342. This lower gneiss has by the writer been compared with the oldest red gneiss of Bavaria, called Bojian by Gümbel, and the Grenville series with the overlying Hercynian gneiss series of the same author, which, like the similar rocks in Canada, includes great beds of crystalline limestone, with serpentine, chondrodite and graphite, and contains *Eozoon Canadense*. (American Journal of Science for July 1870, II. l., 90.)

§ 343. Mr. Vennor believes that there is a want of conformity between the lower "system," or the Ottaw agneiss, and the upper "system," or Grenville series, and farther suggests that the rocks of divisions II and III in Hastings

county (§ 333) are "simply an altered condition, in their westward extension, of the lower portion" of this upper or Grenville series; a gratuitous hypothesis, in support of which he offers no argument, and which it is unnecessary to discuss. The only point of relation between these most unlike groups of rocks is that *Eozoon Canadense* is common to the limestones of the Grenville and the Hastings series.

§ 341. Other indications of organic life than *Eozoon Canadense*, have been found in the rocks of the Hastings series. In his original paper on the Eozoon, in 1865, Dr. Dawson announced that in some of the dark-colored impure limestones of this series, from Madoc "there are fibres and granules of carbonaceous matter, which do not conform to the crystalline structure, and present forms quite similar to those which in more modern limestones result from the decomposition of algæ. Though retaining mere traces of organic structure, no doubt would be entertained as to their vegetable origin if they were found in fossiliferous limestones." He noticed also a similar limestone from the same vicinity, which is apparently "a finely laminated sediment, and shows perforations of various sizes, somewhat scalloped on the edges, and filled with grains of rounded silicious sand." Other specimens from the same region were said to have indications on their weathered surfaces, of similar circular perforations, having the aspect of Scolithus or of worm-burrows. Some of these markings from Madoc were subsequently figured by Dawson, and designated "annelid-burrows," with the remark that "there can be no doubt as to their nature," (Dawn of Life, page 140). The position of these is in the Hastings series.

§ 342. The geologist familiar with the crystalline strata of the Atlantic belt, finds all its principal types repeated in the limited region included in Hastings county and its northwestern extension towards the Ottawa. The rocks of division II serve to connect the Huronian of Lakes Superior, Huron and Temiscaming with the similar rocks of northeastern America, where also the mica-schists resembling those just noticed are widely spread. Rocks of this latter

type were noticed in 1824 by Dr. Bigsby, about Lake Lacroix and Rainy Lake, to the northeast of Lake Superior, and both these and the characteristic rocks of the Huronian were then described by that excellent observer, (American Journal of Science, I, viii, 61). These various crystalline strata were, by him, conceived to belong to what, in the language of the time were called "transition rocks." From these descriptions, and from the examination of collections, the writer, while noticing in 1861, the observations of Bigsby, asserted "the lithological and mineral characters of these crystalline strata seem to be distinct from those of the Laurentian system, and to resemble those of the Appalachians." (Ibid, II, xxxi, 395). Subsequently, in 1870, the conclusion was reached that "there exists to the northwest of Lake Superior an extended series of crystalline schists unlike the Laurentian, and resembling those of the White Mountains." (Ibid, II, 1 85). David Dale Owen had noticed and described in 1853, similar crystalline rocks, as seen in Iowa and Wisconsin.

§ 343. Logan, in 1866 pointed a similarity between the rocks of the Hastings series, and certain strata along the eastern base of the Green Mountains in Canada and Vermont, (§ 331). It was moreover evident that these limestones, slates and quartzites of central Ontario had close resemblance with those strata in western New England, which Emmons had called the Lower Taconic series (§ 104–105). Isolated areas of rocks related to these, both geognostically and mineralogically, are found in several parts of eastern North America, and are probably portions of an ancient formation, once widely spread.

Such an area is described by Emmons as occurring at Camden in Maine, where the Lower Taconic rocks, having the same characters as in Berkshire county, Massachusetts, are fully exposed, with a moderate northward dip, in a section showing an estimated thickness of 2000 feet. The quartzite, which forms the lower member, is there divided into two parts by a mass of slates, and is partly conglomerate, while the limestone, with a thickness of two hundred and fifty feet, is both underlaid and overlaid, by slates, de-

scribed as partly silicious, and partly talcose or magnesian, traversed by a granitic vein, and containing in some parts imperfect macles and staurolite crystals. A mass of quartzose conglomerate, four or five hundred feet thick, belonging to the series, and including pebbles of quartz and of granite, appears as an isolated hill, named Megunticook, in the vicinity, and rests unconformably upon the mica-schists of the region which, with their interstratified gneisses and granitic rocks, are by Emmons distinguished as Primary. The limestones of Thomaston, a few miles distant from Camden, are also by this observer declared to belong to the Lower Taconic, to which moreover he refers, with great probability, many of the silicious and argillaceous schists of this part of Maine. The limestones and associated rocks of Cumberland, Rhode Island, are also supposed by Emmons to belong to the same series. (Agriculture of New York, Vol. I, pages 97–101, and American Geology, Vol. II, pages 20–22).

§ 344. Farther to the northeast, along the Bay of Fundy in southern New Brunswick, are numerous exposures of rocks having close resemblances to those of Camden. The strata are much disturbed and eroded, but are seen at several points along the coast, as at Frye's Island, L'Etang Peninsula, Pisarinco, and the mouth of the river St. John. At this last locality is a section along the Green-Head road, on the right bank of the river, described in detail by Matthew and Bailey, in the report of the geological survey of Canada for 1870 (page 38). The strata, with a general southeast dip of about 50°, have a surface-measurement, across the strike, of 4,100 feet, of which 1,500 are limestones, and the remainder chiefly quartzites, often schistose, with argillaceous and somewhat micaceous schists, and occasional hornblendic layers. Considerable masses of conglomerate, with silicious and calcareous pebbles, are also included in the series, the members of which are not improbably repeated by dislocations. The limestones, of which there appear to be several masses two or three hundred feet in breadth, are in part distinctly crystalline and white, or banded with blue and gray colors, and in

part finely granular, grayish, schistose, and sometimes concretionary in structure. They are frequently magnesian, and occasionally contain small masses of pale yellow serpentine, and a silvery white mica. Portions of the limestone are apparently colored by carbonaceous matter, and a bed of impure schistose graphite, which is wanting in the crystalline aspect of the Laurentian graphite, is mined in these rocks, near the falls at the mouth of the river St. John. These limestones have lately yielded to Dr. Dawson the remains of *Eozoon Canadense.*

§ 345. This succession of crystalline limestones, quartzites and slates, is clearly older than the wholly uncrystalline sandstone and shales of Lower Cambrian (Menevian) age, which, with their characteristic fauna, are found in close proximity. These latter strata appear to be in part made up of the ruins of the older schists, and in one section beds of quartzite and conglomerate, believed to belong to the limestone series, appear between the Menevian slates and the underlying Huronian strata. A mile or two away however, the limestone series is seen to rest upon red granitoid gneisses, regarded as Laurentian, and has itself been described, in the report just mentioned, as an upper member of the Laurentian series. It however differs widely from all the rocks of this series and, on the contrary, presents such strong resemblances with those of Hastings county that the writer, after much time spent in examining the two regions, was led to refer them both to the same geological horizon, and to express the opinion that they are identical with the similar crystalline limestones, quartzites and slates of Berkshire county, Massachusetts, and, like the strata of Camden, belong to the Lower Taconic series of Emmons. (Proc. Bost. Soc. Nat. Hist., April, 1875, Vol. XVII, page 509).

§ 346. When, in 1870, the mica-schist series of Lake Superior was compared with that of the White Mountains, the similar rocks previously described in connection with the Hastings series (§ 335) were naturally included. At the same time, from a study of the collections and the descriptions of Mr. Alex. Murray, then in the writer's hands, it appeared that there existed in Newfoundland, between the

Laurentian gneisses and the fossiliferous strata of Lower Cambrian age, a series of several thousand feet in thickness, which included in its lower portion mica-schists and gneisses, and in its upper portion white marbles, limestones and slates, like those of Hastings. Regarding these, at that time, as making but a single group, it was said: "To the whole of these we may perhaps give the provisional name of Terranovan, in allusion to the name of Newfoundland." (Amer. Jour. Sci. II, l. 87.)

§ 347. It was soon apparent that this was a hasty generalization, and that the lower, or mica-schist and gneiss series, was very distinct from the great limestone and slate series, which had been united with it. In two papers published in 1870, the name of Terranovan was cited as a provisional designation for the gnessic series (Chem. and Geol. Essays, pages 194, 275, 276) but in an address on the Geognosy of the Appalachians and the Origin of Crystalline Rocks, delivered before the American Association for the Advancement of Science, in August 1871, the rocks in question were designated simply as the White Mountain series, while the more recent limestone series, not being recognized in the line of section there described, was not considered. (Ibid, page 244).

§ 348. It was however desirable to have a specific designation for this great series of mica-schist and gneiss, which is so conspicuous in American geology, and that of Montalban (from the latinized name of the White Mountains) suggested itself. This name, in the autumn of 1871, was communicated by the writer to his friend and correspondent, Dr. Gümbel, director of the geological survey of Bavaria. This eminent geologist soon after published an extended review and exposition of the essay above referred to, so far as it regarded the succession and the genesis of crystalline stratified rocks. Therein, while giving the characteristics of the White Mountain series, he adopted the writer's suggestion that it "might be called the Montalban system." (*Das Ausland*, Dec. 25, 1871, page 1228; see also the same journal for 1872, pages 231 and 252).

§ 349. The question of the geological age of the strata

both of the White Mountains and the Green Mountains, has been discussed in preceding chapters, where we have seen that these rocks, called Primitive or Primary by Eaton, Emmons and Jackson, were by Mather and the Messrs. Rogers regarded as metamorphosed or altered paleozoic formations (§ 80–82, 122, 123). The latter view, as has been shown, was taken up by Logan, who suggested that the rocks of the White Mountains were probably altered Devonian strata, while those of the Notre Dame range in eastern Canada, the prolongation of the Green Mountains from Vermont, believed to be stratigraphically inferior to the White Mountain rocks, were regarded, in accordance with the opinion of Mather, as the altered representatives of the Hudson River group, with the probable addition of the Shawangunk or Oneida formation. (§ 171–174). The Hudson River group was then regarded as equivalent to the Loraine shales, so that the crystalline schists of the Green Mountains were supposed to belong to a horizon above the Trenton limestone, and to be the stratigraphical equivalents of the uncrystalline Graywacke formation found along their northwestern border. This view, enunciated by Logan in 1849, was still maintained in 1855 (§ 196).

§ 350. The paleontological researches by which the geological survey of Canada was led to conclude that these uncrystalline strata of the Hudson River group, were really older instead of younger than the Trenton limestone, and identical with the Upper Taconic series of Emmons, have been already set forth, and the adoption for them of the name of the Quebec group is noticed in § 201 ; while in § 231, it has been shown that these strata were supposed to be arranged in a great synclinal, traced from Lake Champlain to Quebec, the crystalline rocks forming the hills of the Green Mountain range being described as occupying a second and a third synclinal to the southeast of the first named. The geography of these crystalline rocks is set forth in § 166, 167, and their lithological characters are briefly described in § 172.

§ 351. The geographical distribution of these three synclinals is given in the Geology of Canada, 1863, (pages 709,

710) where it is said that the strata throughout the region in question are in long narrow parallel folds, "with many overturn dips. This latter circumstance makes it difficult to determine which of these folds are synclinal and which anticlinal, inasmuch as the outcrop in both cases presents a similar arrangement. The weight of evidence however at present, goes to show that the strata dip towards the centre of the areas about to be described, and they will therefore be designated as synclinals."

A more detailed account of the rocks in these three supposed synclinals will be found in the report for 1863–66, pages 31–44. Having therein, for the first time divided the fosiliferous strata of the so-called Quebec group, as displayed in the northwest synclinal, into three parts,—designated, in ascending order, as the Levis, Lauzon and Sillery divisions, an attempt was now made to extend these distinctions to the highly inclined and often inverted crystalline strata of the Green Mountain range, described as belonging to the second and third synclinals.

§ 352. It was assumed that certain black argillites, sometimes carbonaceous or plumbaginous, with occasional limestones, represent, in these synclinals, the Levis division, while the Lauzon and Sillery, it was said, "may be considered as a lower and upper copper-bearing formation." The interbedded sulphuretted ores of copper, frequently found, with iron, chrome and nickel ores, in these crystalline rocks, are chiefly confined to belts characterized by the presence of serpentine, diallage, steatite, chlorite, magnesite and dolomite, and from the prevalence of magnesia in all of these, were spoken in the report as the "magnesian bands;" the other rocks of the series being quartzose, feldspathic and epidotic strata, with argilites and certain hydrous mica-schists, often designated nacreous slates. Of two very similar magnesian bands, one was supposed to be included in the base of the Lauzon, and the other in the base of the Sillery division. To the Lauzon division, which thus separated the two, was assigned a very variable thickness. "In some parts the whole mass appears to be scarcely more than 100 feet wide, while in others, it

may reach 2000 or even nearly 4000 feet." This supposition was rendered necessary by the attempt to establish in this region the existence of two distinct magnesian bands, which like the whole attempt to correlate this crystalline series with the uncrystalline Cambrian rocks adjacent, has since been shown to be fallacious.

It is to be remarked that the report of 1866, quoted above, although bearing the name of Mr. Richardson, and embodying his field-notes, was really the work of Sir William Logan, and was the elaboration of his own previously expressed views of the geological structure of the region in question.

§ 353. In order to understand aright the steps by which a more correct view of the geological horizon of the crystalline rocks of the Green Mountain range was attained, it will be necessary to recall the fact that neither the hypothesis of Mather, nor that put forth by Logan subsequent to 1861, admitted the existence in Eastern North America of any rock-formation between the gneiss of the Adirondacks, and the Potsdam sandstone, which was regarded as the base of the New York paleozoic series. The whole of the crystalline strata of the Atlantic belt, except so far as they might belong to that ancient gneiss, were supposed to have resulted from the alteration of the strata of the New York paleozoic series, of which they were believed to be the eastward extension. The existence of the great Huronian group in a position between the paleozoic and the Primary gneiss, had, it is true been recognized on the upper Ottawa, and on lakes Huron and Superior, but was not admitted by Logan as a possible factor in the geology of the Atlantic belt.

§ 354. As early as 1849, Logan had found in the vicinity of Lake Temiscouata, near the head-waters of the river St. John, unconformably overlaid by the Silurian strata of the Gaspé series (§ 175) an older series of sandstones and conglomerates, in which were included pebbles of serpentine and other crystalline rocks, evidently derived from the Green Mountain range. From the geognostical relations of these older detrital rocks, they seemed to belong to the

Sillery formation, of which they had also the lithological characters; but since this conclusion was not to be reconciled with the theory which made the crystalline rocks from which the pebbles had been derived, a portion of the Sillery formation, Logan was led to refer these sandstones and conglomerates to some unknown formation older than the Gaspé series, though newer than the Quebec group. (Report for 1849, pages 56–64, and Geology of Canada, 1863, pages 423, 426, 427).

§ 355. In 1856 however, the writer described the existence in the Levis division of the Quebec group, at Point Levis, of a dolomitic conglomerate, holding pebbles of greenish and purplish slates, sometimes chloritic. (§ 207.) Later, in 1861, he described the occurrence in the Potsdam sandstone of Hemmingford, near the outlet of Lake Champlain, of large pebbles of similar green and black slate. (Amer. Jour. of Science II, xxi, 404). The fragments of slates, from both of these localities, were wholly unlike anything to be found in the Laurentian, and on the contrary resembled those of the Green Mountain range, suggesting irresistibly that these were more ancient than either the Quebec group or the Potsdam sandstone.

§ 356. Eaton, in 1832, had taught that the talcose, chloritic and micaceous schists, with the hornblende rocks and gneisses of New England, belonged, like the gneisses of the Adirondacks, to the Primitive series, (§ 50) and in this was followed by Emmons, who included the above rocks, together with what he called "laminated serpentines," steatites, and certain clay-slates, in the Primary, or, as he subsequently called them, from certain theoretical views as to their origin, the "laminated pyrocrystalline rocks." To this class he referred the crystalline schists both of the Green Mountains and the White Mountains, which he placed not only beneath the New York paleozoic, but beneath the Taconic series (American Geology, I, page 43 et seq.).

§ 357. In 1862 Mr. Thomas Macfarlane who was familiar with the geology of Norway, and had examined in the field, the crystalline rocks of the Green Mountains in Canada, and those of the Huronian series, as seen on Lake Huron,

compared both of these with the Primitive schist formation, which, in Norway, is found between the Primitive gneiss (§ 309) and the lower paleozoic strata. This intermediate series has been by Scandinavian geologists divided into a lower and an upper group, and Macfarlane, while comparing the massive greenstones, quartzites, conglomerates and limestones, which he had seen on Lake Huron, with the lower, suggested that the upper and more schistose division was represented in the crystalline rocks of the Green Mountains. Bigsby, who had been, as we have seen, the first to study and describe the Huronian schists, in the following year, and independently, compared these to the Primitive schist formation of Norway. (Canadian Naturalist, VII, 125; Quar. Jour. Geol. Soc. XIX, 36, and Chem. and Geol. Essays, 29, 269). He did not insist upon the distinction made by Macfarlane, and in fact both the massive and schistose divisions of the Primitive schists, are well represented in the Huronian region of the great lakes. The resemblances between the argillites, white nacreous schists, and greenish compact epidotic rocks of the Slate Islands in Lake Superior, and certain strata of the Green Mountains in Canada, were pointed out by the writer in the Geology of Canada (page 705).

§ 358. The conclusions of Macfarlane (though not the later one of Bigsby) appeared while the volume just mentioned was in press, and were noticed therein, on pages 596 and 616. As regards the resemblances to the rocks of the Green Mountains, allusion was then made to the opinion which had been expressed by Keilhau, that there is in Norway a gradual passage from the Primitive schists to the lower fossiliferous rocks.

A like view was held by H. D. Rogers with regard to the similar rocks designated by him as the Primal crystalline (or Azoic) schists in Pennsylvania. These he declared, in 1858, to constitute "apparently a portion of the Paleozoic system" which, in its downward extension, was supposed by him to graduate into these crystalline schists. Above the latter, which rested upon the Primary or Hypozoic gneisses, Rogers placed two divisions, called the Primal

conglomerate and the Primal older slates, succeeding which, in ascending order, was the Primal white sandstone, regarded by him as the equivalent of the Potsdam sandstone, the base of the New York paleozoic series (§ 4–7). Thus the crystalline schists between the ancient gneiss and the Potsdam, which, in 1840, had been by Rogers included in the Primary (§ 62) were now, in 1858, called paleozoic, though still assigned to the same geological horizon as before. In fact, while seeming to accept the hypothesis of a metamorphic paleozoic series, Rogers now held substantially the views of Eaton and of Emmons as to the existence of a great crystalline series lying above the older gneiss, but below the Potsdam. The similar crystalline rocks of the Green Mountain range, on the contrary, were, according to Logan, the metamorphosed strata of the Quebec group, and belonged to a horizon above the Potsdam sandstone.

§ 359. The crystalline schists which in Caernarvonshire and Anglesea are found at the base of the sedimentary series, were at first, in 1835, included by Sedgwick with the latter, as a lower member of his Cambrian system. In 1838, however, he separated these crystalline rocks from the Cambrian, and henceforth regarded them as belonging to an older series, a view which was shared by John Phillips, (Chem. and Geol. Essays, pages 353, 383). Murchison, following Delabeche, called them altered Cambrian, and having suggested to Logan that the Huronian series of Canada might be the equivalent of these crystalline strata of Caernarvonshire and Anglesea, the name of Cambrian was, for a time, occasionally used by the geological survey as synonymous with Huronian, until Bigsby, in 1863, in a paper already cited (§ 145) showed that the only strata to which the name of Cambrian clearly belonged, were uncrystalline sediments, and that the Huronian rocks were to be referred to a more ancient series, the Primitive schists of Norway. Nicol has maintained, in opposition to Murchison and Giekie, similar views with regard to the rocks of the Scottish Highlands which, according to the writer's observations, are

identical with the primitive crystalline schists of North America. (Ibid., pages 271, 272).

§ 360. The writer, from his studies of these crystalline rocks of Wales expressed, in 1871, the opinion that they are identical with those of the Green Mountain or Huronian series, (Ibid., pages 269, 353, 383). These rocks as displayed in Caernarvonshire, and similar ones near St. David's in South Wales, hitherto regarded by the geological survey of Great Britain as in part altered Cambrian, and in part eruptive, are now shown by Hicks to lie uncomformably beneath the Cambrian, and are referred by him to a lower group named Dimetian, and an upper called Pebidian. According to McKenna Hughes however, these two constitute but a single conformable pre-Cambrian series, the lithological descriptions of which seem to show that, like the rocks of Anglesea, (already classed with them by Sedgwick, and by the writer,) they also belong to the Huronian series. (Proc. Geol. Soc., London, Nov. 21, 1877.)

§ 361. In a paper on the Geology of St. John County, New Brunswick, published in the Canadian Naturalist in 1863, and re-printed in part in the geological report of Canada for 1870–71, page 23, Mr. George F. Matthew described, under the name of the Coldbrook group, a great mass of crystalline strata found in southern New Brunswick, to the east of the river St. John. These rocks repose on the Laurentian, and underlie unconformably the uncrystalline Lower Cambrian slates of the city of St. John, which include, near their base, conglomerates holding fragments of the Coldbrook group. From this, and from their lithological characters, these older rocks were, by Matthew, referred soon after to the Huronian series. (Quar. Jour. Geol. Soc. Nov., 1865). They have since been found to rest unconformably upon the Laurentian, pebbles of which are contained in the conglomerates of the Coldbrook group.

§ 362. In the paper which contained his account of the Coldbrook group, in 1863, Mr. Matthew described a second belt of crystalline rocks similar to these, to which he gave the name of the Bloomsbury group. These, apparently resting upon the Menevian, and conformably overlaid by

the fossiliferous Devonian sandstones of St. John, were, at that time, called by him altered Devonian strata. In 1869 and 1870, however, the writer devoted some weeks, in connection with Prof. L. W. Bailey and Mr. Matthew, to the investigation of the geology of southern New Brunswick, when it appeared that the Bloomsbury rocks were but a repetition of the Coldbrook group on the opposite side of a closely folded synclinal holding Lower Cambrian sediments. Accordingly, in the geological report of the gentlemen just named, both of these belts were designated as Huronian; in which were now also included two other subdivisions of crystalline rocks found in that region, and previously designated the Coastal and Kingston groups. (Report of Geol. Sur., 1870–71, pages 27, 60, 64).

§ 363. These Huronian rocks were traced in 1869 and 1870 along the southern coast of New Brunswick, from the head of the Bay of Fundy to the confines of Maine, as was stated by the writer in July, 1870, when these rocks, "called Cambrian and Huronian by Mr. Matthew," and characterized by the occurrence of diorites and quartziferous feldspar-porphyries, were said to occur in Eastport, Maine, and in Newbury, Salem, Lynn, and Marblehead, Massachusetts. (Amer. Jour. Science, II, l, 89). In October of the same year, after a further study of these rocks in the vicinity of Boston, and at Newport, they were described as follows by the writer in the Proceedings of the Boston Society of Natural History, (vol. XIV, pages 45, 46).

§ 364. The crystalline stratified rocks in question, it was said, "may be separated lithologically into two divisions, the first being the quartzo-feldspathic rocks. Among these are included the felsite-porphyries of Lynn, Saugus and Marblehead, with their associated non-porphyritic and jasper-like varieties, the compact feldspar of Hitchcock, who has well described these rocks in the Geology of Massachusetts, pages 664, 667. Associated with them is a granular quartzo-feldspathic rock, which is often itself porphyritic, with feldspar crystals, and sometimes appears as a fine-grained syenitic or gneissoid rock, often distinctly stratified. This has been described by Hitchcock as intermedi-

ate between porphyry and syenite; his syenites with a nearly or quite compact feldspar base, and some of his porphyritic syenites, (Ibid., pp. 668, 669) will probably be found to belong to these granular eurites, which I connect with the porphyries. These rocks are seen intimately associated with the porphyry on Marblehead Neck; also in Marblehead, and underlying the argillites of Braintree and Weymouth."

§ 365. The second division of these rocks "includes a series of dioritic and chloritic rocks, generally greenish in color, sometimes schistose, and frequently amygdaloidal. They often contain epidote, quartz and calcite, and occasionally actinolite, amianthus, scaly chlorite and copper-pyrites. This series holds * * serpentine in Lynnfield, where bedded serpentines, dipping at a high angle to the northwest occur, apparently in the strike of these dioritic and epidotic rocks, which include the greenstones of Dr. Hitchcock, described by him as occasionally schistose, and passing into hornblende slate, (Ibid. pp. 548, 647); and also his varioloid wacke, under which name he describes the green and chocolate-colored amygdaloidal epidotic and chloritic rocks of Brighton, and the somewhat similar rocks of Saugus, which are seen within a few hundred feet to the northwest of the limit of the red jaspery petrosilex. This series of magnesian rocks is apparently identical with that which occurs with dolomite and massive dark-colored serpentines, in the city of Newport, Rhode Island, where the beds have also a high dip to the northwest."

§ 366. "A similar series of strata is largely displayed on the islands, and along the shores of Passamaquaddy Bay. The dioritic and chloritic beds towards their base are there interstratified with red felsite-porphyries * * * * which, associated with granular eurites, form great masses in that region. I regard these two types of rocks as forming parts of one ancient crystalline series, which is largely developed in the vicinity of Boston, and may be traced at intervals from Newport to the Bay of Fundy, and beyond. To this same series I refer the great range of gneissic and dioritic rocks, with serpentines, chloritic, talcose and epi-

dotic schists, which stretches through western New England"—that is to say the Green Mountain range.

§ 367. These rocks were then described as "penetrated by intrusive granites, generally more or less hornblendic—the syenites of Hitchcock and others. They often contain two feldspars, as in the well-marked granite of Newport, Rhode Island, which there cuts the greenish dioritic and sometimes amygdaloidal rocks." The granites of Cape Ann and Quincy are there said to belong probably to this class, besides which examples are seen "at Stoneham and in Marblehead, where they intersect the greenish chloritic rocks, and on Marblehead Neck, where they are erupted among the felsite-porphyries."

The crystalline rocks of this ancient series were shown to be overlaid by the uncrystalline sandstones, conglomerates and argillites, including those which at Braintree hold a Lower Cambrian fauna, and rest upon the felsite-porphyry.

§ 368. The feldspar-porphyries above described were by the late Dr. Hitchcock in 1844, classed among unstratified rocks, which had "once been melted." In this class also he placed the whole of the so-called syenites and greenstones, which were made by him to include, besides truly eruptive masses, many indigenous rocks. The serpentines and amygdaloids were, however, correctly described as stratified rocks.

Another type of rocks, apparently distinct from the Huronian series, and occupying a small area on Marblehead Neck, was described in the above pages as thin-bedded quartzites, holding dark micaceous layers, and becoming gneissoid in aspect. These, which were supposed to be newer strata than the Huronian, are also cut by intrusive granites, which, in their turn, are intersected by eruptive greenstones, having a general resemblance to certain indigenous rocks of the ancient series.

§ 369. The petrosilex rocks of the above series were further described in February, 1870, in the following language: "Felsites and felsite-porphyries are well known in eastern Massachusetts, * * * and may be traced from Machias and Eastport in Maine, along the

southern coast of New Brunswick, to the head of the Bay of Fundy, with great uniformity of type, though in every place subject to considerable variations, from a compact jasper-like rock to more or less coarsely granular varieties, all of which are often porphyritic from feldspar crystals, and sometimes include grains or crystals of quartz. The colors of these rocks are generally some shade of red, varying from flesh-red to purple; pale yellow, gray, greenish and even black varieties are however occasionally met with. These rocks are, throughout this region, distinctly stratified, and are closely associated with dioritic, chloritic and epidotic strata. They apparently belong, like these, to the great Huronian system." (Amer. Jour. Science, III, i, 84).

§ 370. The composition of these rocks is shown by the following hitherto unpublished analyses of three typical specimens, collected by the writer, which were made by a former assistant, Mr. Gordon Broome. I. was a pale red compact variety, with feldspar crystals, and had been described as a "porphyritic slaty quartzite," from the Coldbrook group near St. John, New Brunswick; II. was a similar, but darker red variety from the same vicinity; III. was a purplish-red fine grained and homogeneous variety from Newbury, Massachusetts. The analyses were made the aid of fluorhydric acid, and the silica determined by difference:

	I.	II.	III.
Silica,	81.66	79.82	79.63
Alumina,	7.43	8.87	9.67
Ferric oxyd,	2.20	3.86	2.87
Lime,	1.43	.04	.20
Magnesia,	.71	1.83	.61
Potash,	4.64	3.86	5 10
Soda,	1.72	1.58	1.45
Volatile,	.21	.14	.47
	100.00	100.00	100.00
Specific gravity,	2.641	2.666	2.628

Their chemical composition indicates that these rocks are composed chiefly of orthoclase and quartz, a conclusion

which is confirmed by the microscopic study of the compact or crypto-crystalline varieties.

§ 371. It was, as we have seen in 1870, that the Huronian rocks of the Atlantic coast were declared to be the equivalents of the Green Mountain series. In the writer's address to the American Association for the Advancement of Science in August, 1871, this view was developed more at length, and an attempt was made to trace, from the facts then known, this Green Mountain or Huronian series, from Eastern Canada through New England into Pennsylvania, and thence into North and South Carolina. (Chem. and Geol. Essays, pages 243–250).

In 1875, while examining the South Mountain to the west of Gettysburg, in Pennsylvania, he discovered a remarkable and hitherto unrecognized area of the Huronian series, characterized by a great development of the petrosilex-porphyry, which was thus described in August, 1876: "There is here found a great breadth of this rock, distinctly bedded, presenting different varieties, and alternating with dioritic or diabasic, epidotic and chloritic rocks, and with argillites, in which are sometimes included thin beds of the petrosilex; the strata generally dipping at high angles to the southeast." These were then compared with the similar strata along the Atlantic coast, from Rhode Island to New Brunswick, "interstratified, as in the South Mountain, with rocks having the characters of the Huronian series, to which great division I have provisionally referred these bedded petrosilex rocks, with the suggestion that they probably occupy a position near the base of the series." (Proc. Amer. Assoc. Advan. Science, 1876, pp. 211, 212.)

§ 372. These rocks were then declared to be identical in lithological characters with the hälleflinta, or stratified flint-rock, of the Swedish geologists, which is by them assigned to a horizon just above the more ancient or Primitive gneiss, and is important as including in Norway the most considerable deposits of crystalline iron ores. These same rocks are met with in various localities in the Huronian series, on the upper lakes, and are well displayed, as observed by the writer, in a small island lying a little to the south

of St. Ignace island, and for some distance along the shore of the adjacent mainland, to the southwest.

§ 373 In the same paper these petrosilex rocks are compared with the iron-bearing quartziferous porphyries of southeastern Missouri, a comparison previously made more at length by the writer in a review of the Report for 1873 on the geological survey of that State. (Am. Naturalist, April, 1875.) The isolated hills which there rise through the horizontal Cambrian strata deposited around their base, are in some cases of quartziferous porphyry, and in others of a granitoid rock, sometimes capped with the porphyry, which is regarded by Prof. Pumpelly as a younger and a stratified rock. While, for the most part, a petrosilex, sometimes spherulitic, and often porphyritic, it may, as was observed by the writer at Shepard Mountain, become gneissoid from a considerable admixture of crystalline quartz, interlaminated with a red granular orthoclase. In one locality these rocks include layers, sometimes several inches in thickness, of pink and greenish crystalline carbonate of lime, interstratified with a jaspery schistose variety of petrosilex, which, in some layers, is intimately mingled with the carbonate of lime. In the Pilot Knob, beds of argillite, sometimes more or less talcose in aspect, are found with the porphyritic petrosilex.

§ 374. Epidote, chlorite, and a steatitic mineral are occasionally met with in these petrosilex rocks, and magnetic and specular oxyds of iron occur disseminated, in interstratified masses, and in veins intersecting the strata, as has been well described by Dr. Schmidt in the report already named. Oxyds of iron, in some instances manganesian, are also found forming the base of a porphyritic mass, which holds crystals of orthoclase and grains of quartz, suggesting to Prof. Pumpelly the hypothesis of a replacement of the petrosilex itself by these metallic oxyds. He however inclines to another hypothesis, suggested by the admixture of carbonate of lime with petrosilex, above described, and conceives that both the petrosilex and the iron-ore may have been derived by a metasomatic process from a limestone, parts of which were replaced by the oxyds of

iron and manganese, "while the porphyry now surrounding the ores, may be due to a previous, contemporaneous, or subsequent replacement of the lime-carbonate by silica and silicates." The fact is noted that chemical analysis shows that the remaining porphyry, intimately associated with the ore, or with the limestone, has undergone no change, but retains its normal constitution, corresponding essentially to an admixture of orthoclase with quartz.

§ 375. The northeastward extension of the Green Mountain range in Canada, its disappearance, and its re-appearance in the Shickshock Mountains, have already been described (§ 166, 167). It remains to be mentioned that near the eastern extremity of Gaspé, the rocks of this series, consisting of chloritic and nacreous schists with serpentine, appear in a hill about thirteen hundred feet in height, which has been named Mount Serpentine. It is situated on a tributary of the river Dartmouth, not far from the head of Gaspé Bay, and rises in the midst of the uncrystalline sediments of the Quebec group, where its appearance is probably due to a dislocation. (Geol. of Canada, pages 270, 406.)

§ 376. In Newfoundland, the crystalline strata of the Green Mountain series are largely developed both in the central and northwest parts of the island. Those in the latter region, were studied many years since, and were described in the Geology of Canada as belonging to the altered Quebec group. The facts observed with regard to their geological relations at Pistolet Bay and Bonne Bay, have already been given. (§ 218, 219, 226–229.)

In 1864, Mr. Alex. Murray began a systematic geological survey of Newfoundland, and in his first report, in 1865, described with detail the further distribution of these crystalline rocks, which he continued to regard as the altered equivalents of the middle portions of the Quebec group, occupying a position immediately below the Sillery sandstone. (§ 352).

§ 377. The subsequent researches of Mr. Murray, and of his assistant, Mr. James B. Howley, have however led them to adopt a very different view, which is set forth in

the report of the latter, dated March, 1875, approved by Mr. Murray, and published as a supplement to his own report, in the same year. The conclusions from Mr. Howley's examinations on the east shore of Port-a-Port Bay, about sixty miles southwest of Bonne Bay, are that the lower paleozoic formations of the region, supposed to include Potsdam, Calciferous, Levis and Sillery, are arranged in a series of sharp folds, ranging N. 22° E.; "the whole mass of strata having, towards the close of the later deposits, or subsequently, been affected by vast igneous intrusions, and become much dislocated by a set of great parallel or nearly parallel faults, the general trend of which is northeast and southwest. At the summit of the whole series is a great volume of igneous and magnesian rock, consisting of various diorites, serpentines and chlorites, which our evidences seem to indicate to be lapped over the inferior strata unconformably, and to come in contact with different members at different places."

§ 378. In the succeeding pages of the report, as in the geological map of Newfoundland, published in 1876, this whole magnesian series is designated as "serpentines," or "ophiolites," and we read, "further to the northward, the sandstone group was invariably seen to pass below the serpentines, which were wrapped over the former in a confused and irregular mass, the points of contact differing at different points in such a manner as could only be accounted for by supposing the ophiolites to be unconformably related." (Report on the Geol. of Newfoundland, 1875, pages 52, 54).

§ 379. In a note affixed to Mr. Milne's paper on the geology of Newfoundland, in the Geological Magazine for June, 1877, (page 256), Mr. Murray quotes the language of the first of the above extracts, as expressing his latest opinions on the relations of the rocks in question. He says, moreover, of the Sillery sandstone, "while we find it to succeed the Levis formation with perfect regularity, although with numerous folds and twists, in every case it seems to pass below the serpentines, wherever a contact is seen, and in every case to pass below them unconformably." He further concludes from the presence, in the vicinity of Port-a-Port Bay, of

comparatively undisturbed beds holding a fauna of Trenton, and perhaps of Loraine age, that "the great igneous intrusion * * * must be nearly at the age of the Chazy, or perhaps later; that it has been the metamorphosing agent; and that the altered strata, consisting of chloritic slates, serpentines, melaphyres, diorites, etc., belong to a horizon somewhere intermediate between the Chazy and Hudson River [Loraine] group."

§ 380. The observations made at Bonne Bay, (§ 218), where, on the northwest side of a hill of these serpentinic strata, the Sillery sandstone, overlying conformably the fossiliferous rocks of the Quebec group, is seen to dip southeastwardly, as if to pass beneath the crystalline series, is cited by Mr. Howley in favor of the above view. No reference is however made to the different condition of things described at Pistolet Bay, (§ 219, 227,) where, on the contrary, or southeastern side of a similar area of crystalline rocks, the Sillery sandstones are said to be found, occupying a breadth of some miles. Their attitude in this locality is not recorded, but a little further south, along the eastern coast, the same sandstones appear in the island of St. Julien, succeeding the serpentinic series, though without visible contact, and dipping away from it to the southeast.

§ 381. The facts already set forth show that neither the view of Logan, nor the later one put forth by Murray and his assistant, is admissible, but that the crystalline rocks, formerly described as belonging to the "altered Quebec group," like the similar rocks of the coast of New Brunswick, and Massachusetts, belong to a series older than the uncrystalline strata known as the Quebec group. Upon this ancient crystalline series, there was deposited unconformably the Sillery sandstone, succeeded by the Lauzon and Levis divisions. In the interval between this last and the Trenton age, came a time of disturbance, producing great northeast and southwest folds and dislocations, with overturns to the northwest, and upthrows on the southeast side. As a result of these movements, the Cambrian strata on the northwest side of the belt of older crystalline rocks are very generally found to be inverted, and, in parts, are

over-ridden by the pre-Cambrian strata, beneath which they now appear to pass unconformably, as in the sections at Port-a-Port, Bonne, and Pistolet Bays, already described, where the existence of such dislocations, with upthrows in the southeast side, has been pointed out (§ 219).

The structure above described is well known to be almost universal along the whole northwestern border of the Atlantic mountain belt, from Canada to Alabama, and has been described at length by various observers (§ 15, 16, 71-81, 177—179).

§ 382. It may be added that the investigations of the geological survey of Canada, during the years 1876 and 1877, have, according to the director of the survey, demonstrated the correctness of the view, so long maintained by the writer, that the crystalline rocks of the Green Mountain series belong to a more ancient system, which underlies unconformably the uncrystalline Cambrian sediments of the Quebec group.

The unpublished observations of Prof. William B. Rogers upon the similar strata in Virginia are to the same effect, and the writer is permitted, in this connection, to print the following extract from a letter addressed to him by this eminent geologist, and dated Boston, June 8, 1877:

§ 383. "The sections which I had the pleasure of showing you lately, illustrating the position of the Lower Cambrian beds (our Primal conglomerate, etc.) in their contact with the crystalline and metamorphic rocks of the Blue Ridge in Virginia, form part of a series embracing the results of some forty transverse explorations, made during and since the Virginia geological survey, at nearly equal distances across the chain, from Harper's Ferry to the North Carolina line. In many of these sections the unconformity of the Cambrian upon and against the crystalline and metamorphic rocks is unmistakable and conspicuous; the lower members of the Primal being seen to rest on the slope of the Ridge, with northwest undulating dips, on the edges of the steeply southeastward-dipping older rocks. In other cases, the Primal beds, thrown into southeast dips in the hills which flank the Blue Ridge, are made to underlie, with

more or less approximation to conformity, the older rocks forming the central mass of the mountain. But even in these instances it is, I think, not difficult to discern the true relations of the strata. As interesting examples of the phenomena referred to, I would mention the sections exposed at Vestal's, Gregory's, Snecker's, and Manasses Gaps, and Jeremie's Run, in the northern part of the Blue Ridge; and at Dry Run, Turk's, Tye River, White's, James River, Point Lookout, Fox Creek, and Whitetop Mountain Gaps, in the middle and southwestern prolongation of the chain."

§ 384. The crystalline rocks which are the prolongation of the Blue Ridge into southern Pennsylvania, have already been described as Huronian (§ 371). Prof. W. M. Fontaine, who, in his late excellent papers on the geology of the Blue Ridge in Virginia, has confirmed the conclusions of W. B. Rogers as to the unconformable superposition, and frequent inversions of the lower paleozoic rocks along its western base, describes the Blue Ridge as having an axis of granitoid gneiss, referred by him to the Laurentian, which is seen near Lynchburg, and in the Peaks of Otter, and further southwestward. Resting unconformably on both sides of this ancient series is a group of crystalline schists, which, to the northward, conceal the Laurentian, and are by him compared to the Huronian. To the eastward of the Laurentian, and apparently occupying a synclinal in the schists just mentioned, is a folded series of limestones, with quartzites, micaceous schists and roofing-slates, like the Lower Taconic rocks of Berkshire county, Massachusetts, and apparently the prolongation of the Taconic belt noticed by Emmons to the east of the Blue Ridge in North Carolina, which he declared to extend northward through Virginia. Beyond this, designated the middle belt, Fontaine describes an eastern belt of granitoid gneiss overlaid by a series of mica-schists, with gneisses often hornblendic, and said to have the characteristics of the White Mountain series. These are displayed in broad undulations, with moderate east and west dips, and are less disturbed than the Huronian rocks which lie further to the west. (Amer. Jour. Science

III, ix, 14, 93, 361, 416, and Harper's Annual Record for 1875, pages c.—cii).

§ 385. We have seen that in 1866 the South Mountain and the Welsh Mountain of Pennsylvania,—the Northern and Middle gneissic districts of H. D. Rogers—were already regarded as Laurentian (§ 44). In 1876, the writer presented to the American Association for the Advancement of Science the results of some observations made during the previous year, in the Southern gneissic district, as seen on the Schuylkill to the northwest of Philadelphia. The rocks hitherto described as the northern division of this gneissic district (§ 23) were now declared to belong to a third Laurentian belt, lying further to the southeast, but nearly parallel with the preceding ones.

§ 386. It was said: "This Laurentian belt, which is not more than a mile wide on the river, [near Conshohocken, on the Schuylkill,] separates the Auroral limestones of the northwest from the Philadelphia gneisses and mica-schists, which are typical rocks of the Montalban series. The Laurentian gneiss, much contorted, and in parts nearly vertical, is succeeded on the southeast side, after a little interval in which the rocks are concealed, by a belt having all the characters of the Huronian series, in which are included the large steatite quarries on both sides of the Schuylkill. These are associated with dark-colored serpentines, chloritic schists, unctuous mica-schists holding garnets, feldspathic and hornblendic rocks, and argillites; the section presenting most of the typical rocks of the Huronian, in very highly inclined strata, which from the data given by Rogers, seem to have a strike somewhat different from that of the Laurentian gneisses."

§ 387. "This section along the Schuylkill has the advantage of offering, within a short distance, and in a very accessible place, characteristic exposures of three great series of crystalline formations. The intermediate position of the Huronian in this section seems to show that its stratigraphical place is below the Montalban, and it is to be noted that the dips—generally moderate—of the great breadth of Montalban strata, on the one side, and of the Auroral lime-

stone on the other, are towards what we may call the Laurentian axis. * * * It would seem as if the Laurentian gneiss had formed a barrier, by the resistance of which the unconformably overlying formations have been thrown into folds, and in many cases faulted, so that they are made made to dip, on either side, towards the axis."

§ 388. "The Primal slates and sandstones of Rogers, which underlie the Auroral magnesian limestone, present many points of great interest. In some places, as at Chiques on the Susquehanna, and below Reading on the Schuylkill, (where they are seen to rest on the Laurentian) they are apparently several thousand feet in thickness, while elsewhere along the South Mountain, their only representative is a few feet of detrital sandstone, interposed between the Auroral limestone and the gneiss." "The crystalline character often exhibited by these so-called Primal strata, was noticed by Rogers, who ascribed it to their subsequent alteration by intrusive rocks. A careful study of this series has however convinced me that its detrital beds include, in many parts, deposits of chemical origin, such as beds of crystalline magnesian limestone, often holding serpentine, chloritic, steatitic, and micaceous schists, and especially great beds of magnetic, and more rarely specular or red hematite iron ores. * * * The aspect of these ores, and their associated rocks, is unlike that of the other crystalline series already mentioned." "These strata include deposits of carbonate of iron, and others of pyrites, from the alteration of one and the other of which, in the deeply decayed portions of these strata, (now converted into clays) have been formed the great quantities of hydrous iron ores which characterize, throughout the whole extent of their outcrops, the Primal and Auroral strata. These are the Lower Taconic rocks of Emmons."

§ 389. The intercalation of crystalline limestones with the detrital beds and the crystalline schists of the Primal, was noticed by H. D. Rogers, who speaks of "the limestones at the passage of the Primal into the Auroral," and elsewhere of "the alternations of Primal slate and Auroral

limestone" (§ 35). These two divisions must in fact, be regarded as making but a single geognostical series.

The history both of the crystalline iron-ores and the brown hematites of the Primal and Auroral rocks had, previous to the above publication, been discussed more at length by the writer. These rocks, although distinct alike from the Montalban, Huronian, Norian and Laurentian series, present certain mineralogical and lithological resemblances with each of these. The unctuous schists of the Primal and Auroral, called by Emmons talcose and magnesian, have much likeness to certain schists in the Huronian. Hence it was, that after examining, for the first time, in 1874, the highly inclined, soft and decaying micaceous schists enclosing the limonites of Fogelsville, Pennsylvania, which are found in the Auroral limestone,—regarded by Rogers as occupying a position between the Potsdam and the Trenton formations of the New York series,—the writer insisted that these crystalline schists are very unlike anything found elsewhere at this geological horizon, and suggested that they belonged to an older crystalline series, which might be Huronian.

§ 390. In support of the view of the Eozoic age of these limonite-bearing strata, he recited the observations of Prof. C. U. Shepard who, in 1837, declared, with regard to the well-known deposits of limonite in Salisbury and Sharon, Connecticut, that "the ore is disposed in vast beds, with a stratification everywhere obvious, and perfectly conformable to that of the adjoining mica-slate. It is moreover free from secondary aggregations." In the town of Kent, similar ores, in parallel, highly inclined layers, were said to be included in a deposit known as fuller's earth, which, according to Shepard, is a decomposed micaceous gneiss. In other localities in this region the limonites appears as the cement to a breccia containing fragments of quartz. The source of these ores, it was suggested by Shepard, is to be found in the decomposition of sulphuret of iron, and other ferriferous minerals, and he adds "it is obvious that in a majority of instances, the change took place in the original

repositories of these minerals." (Mineralogy of Connecticut, pages 17, 20, 146).

§ 391. In further illustration of this point the writer referred to the limonite ores formerly mined along the Blue Ridge, in Carroll county, Virginia, and Ducktown, Tennessee, which are clearly of epigenic origin, and the oxydized outcrops of pyritous lodes, which, at greater depths, have since been exploited for copper. These rocks he had already described as being of Montalban age, to which were also referred the similar gneisses of the Hoosac Mountain, in Massachusetts, in the decayed portions of which was found a layer of limonite ore. The fact was then recalled that all of the various crystalline series of the Atlantic belt contain pyrites, often interbedded in great masses. Of these crystalline rocks it was said, "the Huronian schists occasionally include beds of carbonate of iron, and others of magnesite and dolomite abounding in carbonate of iron, sometimes with much carbonate of manganese. Emmons moreover, thirty years since, noticed the deposits of carbonate of iron in the limestones and talcose schists of his Lower Taconic rocks, to which, according to him, the limonites of western Massachusetts and eastern New York belong. From the decomposition and oxydation of these various minerals, whether sulphurets or carbonates, hydrous peroxyds will result, and hence we should expect to find them wherever these decayed rocks have escaped erosion." (Trans. Amer. Inst. Mining Engineers, III, 419, 420).

§ 392. Subsequent studies in 1875, in Pennsylvania, made it clear that the decayed crystalline schists which there contain the limonites, were not Huronian but Taconic. These conclusions were set forth in a paper on The Cornwall Iron Mine, and some related deposits, read before the Institute of Mining Engineers in February 1876, and published in the Transactions (IV, 319–325).

It was there said that the crystalline magnetic and specular iron ores, represented by the mines of Cornwall, Dillsburg, and Boyertown, and the Warwick and Jones mines, found along the borders of the Mesozoic basin of Pennsyl-

vania, are not to be confounded with the ores of Huronian or of Laurentian age, but "alike by their geological position and their mineralogical associations differ from those, * * and appear to belong to a distinct ore-bearing horizon." "These ores were by Prof. H. D. Rogers referred to what he designates as the Primal slates, * * though by some later observers, the Cornwall mine, and certain related deposits west of the Susquehanna, have been referred to the Mesozoic sandstone." The conclusion then reached however, was that "they are, all of them, really contemporaneous deposits included in the Primal slates, which correspond to a portion of the Lower Taconic series of Emmons, and belong, in my opinion, to a lower horizon than the Potsdam sandstone of the New York system." "These magnetic and specular ores of the Primal slates have very close geological relations with the brown hematites of the region, some of which belong to the same Primal slates. These ores, which I believe to come from the alteration of deposits of carbonate, and, in many cases, of sulphuret of iron, oxydized *in sitû*, are, in certain deposits of the region, interstratified with crystalline magnetic and specular oxyds; the whole being imbedded in the clays which have resulted from the more or less complete decomposition of the enclosing crystalline rocks."

§ 394. The micaceous substance which makes up a considerable part of the residue remaining after the decay of these schists (which are often impure limestones,) has been found by Genth to have, in many cases, the composition of a hydrous non-magnesian potash-mica, referred by him to the species damourite. This however is not always the case, since both talc and chlorite are found in the Primal slates of the Cornwall mine, and chlorite, with garnet, in those of the Jones mine. The latter moreover includes beds of an apparently decayed rock, which has been mined as an ore of copper, and consists in large part of a soft pale green mineral, in minute scales, resembling in aspect the hydrous mica above mentioned. Analysis however shows it to be a hydrous silicate of alumina, ferric and cupric oxyds, and magnesia, constituting a kind of copper-chlo-

rite, which has been described by the author as a new species, under the name of venerite (Trans. Amer. Inst. Mining Engineers, IV, 326.)

§ 395. The soft and unctuous schists of the Taconic were by Emmons designated magnesian slates or talcose slates, and the latter name was also given to the somewhat similar schists found in the Huronian series, with which the former were generally confounded, although Emmons clearly distinguished between the talcose slates of the Taconic, and those of what he called the Primary rocks. In 1855, the writer, having examined many of the talcose slates, from both series, announced that they contained little or no magnesia, and were essentially hydrous silicates of alumina, belonging to the class of minerals represented by pyrophyllite, pholerite, etc. To avoid the perpetuation of an error, he therefore proposed for these unctuous aluminous schists, in allusion to their pearly lustre, the name of nacreous slates (Amer. Jour. Sci., II, xix, 417).

§ 396. Emmons soon after described, in 1856, the occurrence of a soft compact mineral, locally known as soapstone, which, according to him, occurs in many parts of North Carolina, interstratified with the quartzites, talcose slates and limestones of the Lower Taconic series, in which it "takes the place of steatite." This substance, which is white, or greenish-white in color, and sometimes holds crystals of magnetite, having been analyzed by Dr. C. T. Jackson, was found to be essentially a hydrous silicate of alumina, and by him referred to agalmatolite, a name which was adopted by Emmons. (Geol. Midland Counties, N. Car., pages 52–55, 127, and Proc. Bost. Soc. Nat. Hist., VI, 33). Brush, in 1858, showed that what had hitherto been called agalmatolite, was really but a compact pyrophyllite, which he correctly described as an aluminous talc. (Amer. Jour. Sci. II, xxvi, 68).

§ 397. It thus appears that besides the foliated magnesian minerals, talc, chlorite and venerite, all of which are occasionally met with in the Taconic schists, these are various micaceous hydro-silicates of alumina, including pyrophyllite and damourite, which either pure, or mingled with quartz,

enter into the composition of the so-called talcose-schists, originally designated nacreous slates by the writer, and now frequently spoken of as hydro-mica slates.

§ 398. As regards the relation of the Lower Taconic series to organic life, it is well known that the Primal white sandstone, in various localities from Massachusetts to Tennessee, contains a form described as Scolithus, of which the history has been given at length, (§ 266). In a communication by the writer, in the Proceedings of the American Association for the Advancement of Science for 1876, (page 208), it was stated that Prof. Prime had lately found in the Auroral limestone of Pennsylvania, besides an undescribed Lingula, certain casts which Dr. Torell, after examination, regarded as generically identical with those found in the Eophyton-sandstone of Sweden, and supposed to belong to a radiate animal, to which he had given the name of *Monocraterion*, (§ 256). It is not improbable that these casts in the limestone in Pennsylvania may be due to the same organism which has produced the Scolithus of the Primal sandstone. The relations of this Primal and Auroral series, both to the Eophyton-sandstone of Norway, and to the series of limestones, talcose-slates and quartzites which are found in southern Norway, at the base of the Cambrian series, and are by Kjerulf named Lower Taconic, (§ 257), are subjects for further inquiry.

Under the name of *Palæotrochis*, Emmons, in 1856, described what he conceived to be a silicious coral, found in the quartzites of the Lower Taconic in Troy, Montgomery county, North Carolina, but there does not seem to be any good ground for regarding it as of organic origin. (Geol. of the Midland Counties of N. Car., page 60; and Chem. and Geol. Essays, page 411).

§ 399. We have given reasons for regarding the Lower Taconic, or the Primal and Auroral strata of the great Appalachian valley, as the equivalents of the similar series in southern New Brunswick, (§ 344), and of the Hastings series in Ontario, (§ 331, 341), with its *Scolithus* and *Eozoon*. While it has been shown, in a preceeding chapter, that the Upper Taconic includes the organic remains of the European Cam-

brian, at least as low as the Menevian, it is by no means certain whether the Lower Taconic series is to be regarded as the equivalent of the still lower beds of the Cambrian of Great Britain and Sweden. In this uncertainty it is deemed well to preserve for this series the original name of Taconic, or better, Taconian. (Proc. Bost. Soc. Nat. Hist., XIX. 278).

§ 400. Some recent observations by the writer on the crystalline rocks of the Blue Ridge, are given in a communication to the Boston Society of Natural History. (Proceedings, etc., XIX, 277.) After noticing the presence of rocks both of Montalban and Huronian ages, on the line of the Baltimore and Ohio railroad, (the latter near Harper's Ferry,) and the existence of Laurentian gneisses at Bellisle, near Richmond, Virginia, some account is given of the crystalline rocks seen in a section across the Blue Ridge, in Mitchell county, North Carolina.

"The gneisses of Roan Mountain, and similar rocks at its western base, which include the great masses of magnetite, are Laurentian, but indications of a belt of Huronian schists, associated with specular iron-ore, are found on the western flank of the mountain. To the eastward, the Laurentian rocks are succeeded by a great breadth of thin-bedded gneisses, with highly micaceous and hornblendic schists, referred to the Montalban series, in which is included the narrow belt of dunite, or olivine rock, found near Bakersville. These Montalban strata are intersected by numerous endogenous granitic veins, which are largely exploited for mica, and yield, moreover, fine cleavable masses of orthoclase, and of albite, together with beryl, apatite, samarskite, and autunite. The rocks of this series, often deeply decomposed, were found to occupy the greater part of the country, as far east as Salisbury, interrupted, however, near Statesville, on the Western North Carolina railroad, by granitoid gneisses, which have the characters of Laurentian." (For some notice, by the writer, of the metalliferous veins in the Montalban rocks of the Blue Ridge in Virginia, North Carolina and Tennessee, see Transactions Amer. Inst. Mining Engineers, II, 123, and Chem. and Geol. Essays, page 217.)

§ 401. "The belt consisting of granular quartz-rock, with limestones and hydrous mica-slates, which was seen at the eastern base of the Blue Ridge, on the Catawba river near Marion, North Carolina, has all the characters of the Lower Taconic, to which it was long since referred by Emmons. Portions of this quartzite are thinly bedded and flexible, constituting what is known as itacolumite. It is regarded by the writer as identical with the Primal white sandstone of Pennsylvania, which, with the Auroral limestone, and its interstratified and overlying unctuous schists, and the succeeding roofing-slates, constitute a distinct geological horizon."

§ 402. In his report on the Geology of North Carolina, in 1875, and in the colored geological map and sections accompanying it, Prof. Kerr has included the whole of the crystalline stratified rocks of the State under two heads, Laurentian and Huronian. The former of these, both in the text, and in the legend of the map, he divides into Lower and Upper Laurentian, though in the accompanying colored sections, the Lower division is called "granite." The name of Upper Laurentian, originally given by the geological survey of Canada to an entirely different group of rocks, the Norian or Labradorian, is by Prof. Kerr applied to the series of gneisses and micaceous and hornblendic schists, (with included beds of chrysolite-rock,) which is that described by the writer in the above section, as the Montalban, of which it has all the characters; while the rocks of the Roan Mountain, called by Prof. Kerr, Lower Laurentian, are, as already stated, true Laurentian.

§ 403. Under the head of Huronian, Prof. Kerr informs us he has included the Taconic series of Emmons, including the quartzites with the so-called *Palæotrochis*, the itacolumite or flexible sandstone, the hydrous mica-schists, the argillites, often plumbaginous, and the pyrophyllite beds, together with the granular limestones and marbles, often accompanied by limonites. The quartzites of this series, like those of the same horizon in Pennsylvania, often abound in magnetic and specular iron-ores, and sometimes pass into a specular schist or itabirite. This series is de-

scribed by Prof. Kerr as resting upon the Upper Laurentian, (Montalban) and in part made up of its ruins. He has indicated not less than five parallel belts of these so-called Huronian rocks, stretching from northeast to southwest, in North Carolina, one of which includes the Taconian rocks noticed by the writer at the eastern base of the Blue Ridge, in the section described above. It remains to be determined where, and to what extent, true Huronian rocks occur within the limits of North Carolina, but it appears not improbable that some of the more massive portions of the Huronian may be included in the rocks, which under the names of greenstones and feldspar-porphyries, are said by Prof. Kerr, to occur in parts of the so-called Upper Laurentian areas.

§ 404. We may in this place notice the views of Prof. F. Bradley, who, arguing chiefly from a supposed parallelism between the various groups of crystalline rocks and the different paleozoic formations of the Champlain division, has recently been led to put forth anew the old hypothesis of the paleozoic age of the crystalline strata of the Atlantic belt, and to suggest that the Blue Ridge, in North Carolina and Tennessee, consists of altered Cambrian and Siluro-Cambrian rocks (Amer. Jour. Sci. III, ix, 279,370).

To this hypothesis, a conclusive answer is furnished by the observations of W. B. Rogers, and of Fontaine, already quoted, as to the relations of the basal paleozoic rocks to the crystalline schists, and by the express declaration of the latter that certain of these, described by him as argillites, were in their present condition before the Primordial (either Taconian or Cambrian) period, (Ibid. III, ix, 367) as appears from the fact that fragments of these are found, together with feldspathic debris, in the Primordial conglomerates. From this, he concludes that the crystalline rocks of the Blue Ridge formed the southeastern border of the paleozoic sea; while Bradley, on the contrary, imagines these same rocks to be themselves paleozoic strata, which were uplifted and altered after the close of the paleozoic period. The observations of Fontaine are confirmed by those of the writer, who has found in southwestern Vir-

ginia, pebbles of gneiss and of mica-schist, apparently Montalban, in these basal conglomerates (Harper's Annual Record, 1875, pages c—cii).

§ 405. We have already adverted to the fact that the five great groups of crystalline stratified rocks, constituting as many distinct terranes — Laurentian, Norian, Huronian, Montalban and Taconian, necessarily have, notwithstanding their differences, certain lithological resemblances with each other. All of them include quartzites, and crystalline limestones, in which latter certain mineral silicates, such as serpentine, hornblende, and micas are occasionally met with. It is in those aluminiferous rocks which are without lime and magnesia, that are found the essential and characteristic differences, and these depend upon the principle, set forth in detail by the writer, in 1863, of a progressive diminution in the proportion of the alkalies to the alumina, (Chem. and Geol. Essays, page 27) as we pass from the older to the newer geognostical groups. In accordance with this, the feldspars, orthoclase and albite, gradually disappear, being partially or wholly replaced by silicates like muscovite, damourite and paragonite, and finally by andalusite, fibrolite, cyanite, staurolite and pyrophyllite. These various silicates are scarcely known in the Laurentian and Norian, though they are represented to a limited extent, by certain quartzose mica-schists, in the Huronian. In the Montalban, they appear to a considerable extent, and have their most complete crystalline development in certain beds in that series, although orthoclase still predominates in the associated gneisses.

§ 406. In the Taconian rocks, on the contrary, the feldspars are but rarely and exceptionally developed, while hydrous silicates of alumina, such as damourite and paragonite, or pyrophylite, which is destitute of alkali, abound, and either alone or mingled with quartz, or with limestone, form great beds in the series, in which also are found staurolite, chiastolite and cyanite, though generally not so well defined as in the Montalban, which is easily distinguished from the Taconian by its great development of strong mica-schists, well-marked gneisses, and blackish hornblendic

schists. (Chem. and Geol. Essays, page 244). It is by a misconception that some have been led to regard the presence of staurolite, cyanite and andalusite, as exclusively characteristic of the Montalban, a proposition nowhere maintained by the writer, since, although they have not been found in the oldest terranes, these mineral species have long been known to occur, in many localities, in the Taconian schists.

§ 407. The question has arisen whether these crystalline rocks of the Taconian series, occupying a position between the Montalban below, and the recognized Cambrian above, are to be regarded as eozoic, or as paleozoic. In the language used by the writer, in 1876, in answer to this question: "It will be found as difficult to draw the line between the eozoic and paleozoic, as it is to define that between the mesozoic and the paleozoic, on the one hand, or the mesozoic and the cenozoic on the other. There are no hard and fast lines in nature; breaks are local, and there is nowhere an apparent hiatus in the geological succession, which is not somewhere filled." Referring to the *Lingula* of the Auroral limestones, it was then suggested "that this seemingly imperishable type of brachiopods may serve, like the rhizopods, represented by *Eozoon*, as a connecting link between eozoic and paleozoic time." (Proc. Assoc. Advan. Science, 1876, pages 207, 208).

§ 408. We have already noticed in § 119—122 some of the various and contradictory hypotheses put forth with regard to the age of the Taconian or Stockbridge limestones, as displayed in western New England. According to H. D. Rogers, they, like the Auroral limestone of Pennsylvania, are of the age of the Calciferous and Chazy of the New York series, while by Adams and others they have been supposed to be either Lower Helderberg or Devonian. Mather, and later Dana, have maintained that they are of Trenton age, while Logan, in his geological map, published in 1866 (§ 44) has represented them as the Levis division of the Quebec group, or Upper Taconic—the original characters of the limestones, in all cases, being supposed to have been greatly modified by a subsequent process. Of these

four irreconcilable views, each one in its turn, has been plausibly defended upon the ground of apparent superposition to, or of association with fossiliferous strata of different horizons, in one or more localities.

§ 409. It has long been known that the more ancient folded and faulted strata, along the Atlantic belt, include portions of newer formations, of various ages, and moreover that the natural order of the strata is so generally inverted, that the newer formations pass, or seem to pass, beneath the older. Of this, a marked example has been given in § 232, where, in Farnham, in the province of Quebec, the strata holding a Siluro-Cambrian fauna, were assigned a position at the base of the Quebec group. The observations of Wing, and of Billings, have shown the existence of similar examples in western Vermont (§ 205) which have more recently been discussed by J. D. Dana. The similar strata on the eastern side of the Green Mountains, in northeastern Vermont and Canada, referred to by Logan (§ 331), are accompanied by fossiliferous strata of Lower Helderberg or Devonian age.

Further southward, in the valley of Virginia, Devonian and Carboniferous strata become involved in these disturbances, and are seen to dip at high angles to the southeastward, apparently passing beneath the Taconic or Auroral limestones. (Compare Emmons, Amer. Geol., II, 64, and Lesley, Proc. Amer. Philos. Soc., XII, 489).

§ 410. The argument of those who ignore these facts of structure, and adopt the hypothesis of metamorphism, may thus be stated: Fossiliferous strata included in folds, or in faults, are supposed to fix the age of the entire series in question, while the absence of organic remains from other parts of the section is accounted for by the assumed metamorphosis of these parts. The faith of some believers in this hypothesis has frequently led them to mistake obscure and doubtful markings in crystalline rocks, for vestiges of organic life. A striking example of this is afforded by the supposed brachiopods and trilobites, upon which it was at one time attempted to establish the Silurian age of the White Mountain gneisses and mica-schists (§ 123).

§ 411. The late notes of Dana on the geology of Vermont contain some observations on this point, which are not the less instructive that they come from an extreme advocate of the metamorphic hypothesis. Describing a quartz rock, which in New Haven, Vermont, is interstratified in limestones supposed to belong to the Taconic series, he says: "The quartzite is in most parts a little slaty in structure, and in limited portions, a shining grayish-black slate. In places over it are areas of sub-concentric conchoidal lamination, looking somewhat as if examples of the flow-and-plunge structure, but more probably a result of concretionary consolidation. To the latter cause, I attribute some forms that looked exceedingly like casts of a *Pleurotomaria* and a *Murchisonia*, and of a valve of *Orthis lynx*. Others of these imitative forms, over the surface, were semicylindrical and chambered, as if worn casts of long crinoidal stems, yet having the chambers too large and irregular for any known crinoidal forms. These simulations of crinoids may also be due to a concentric structure in the slaty portion of the rock, yet how, it is not easy to understand." (Amer. Jour. Sci. III, xiii, 409).

§ 412. Dana has, in this connection, given a figure of natural size, of a portion of one of these chambered cylinders, which had a total length of twenty-five centimeters. It is represented as divided by transverse septa of about one millimeter in thickness, into chambers having a length of three centimeters, more or less, and a breadth of six centimeters. The walls of the cylinder, in the drawing, are not distinguished from the enclosing rock. The figure bears such a close resemblance to the transversely waved or grooved casts of so-called Scolithus from the Primal sandstones of Pennsylvania, (§ 266, 268), which probably belong to the same horizon, that it seems highly probable that these hollow casts may be due to the same cause, and that they are of organic origin.

§ 413. It is not improbable that the Taconian rocks may include other forms than Scolithus and Monocraterion, and the undescribed linguloid shell. In their study, however, it is necessary to beware, on the one hand, of mistaking such con-

cretionary markings as those already mentioned, for organic remains, and on the other to avoid the error of referring to these older rocks, what are perhaps portions of newer strata resting upon them, or involved in their folds or dislocations. The rocks thus brought together may differ so widely in lithological characters that it is easy to discriminate between them, but in other cases the task is much more difficult, as in the example of some fossiliferous Silurian beds in southern New Brunswick, made up almost wholly of the disintegrated Huronian greenstones, in the midst of which they were deposited. Another example is that of the Trenton limestones of Hastings county, Ontario, which resemble so closely some of the bluish-gray earthy beds of the underlying Taconian, that it is very easy to mistake the one for the other (§ 333). The difficulty of distinguishing between these two formations would be greatly enhanced were the newer rocks involved with the older in a series of folds, inversions and dislocations, as in the case in the Appalachian valley. When we add to this, the of process decay, which has converted the slaty and impure portions of the Auroral limestone, for considerable depths, into a soft and yielding material, it is evident that the localities of fossiliferous limestones in such a region should be scanned with the greatest care.

§ 414. Prof. Prime, in a late paper on the limestones of this valley, in Lehigh and Northampton counties, Pennsylvania, after mentioning the Monocraterion and Lingula, already pointed out (§ 398,) each of which has been found only at one locality in Lehigh, notices the occurrence, in the same county, of a single *Orthoceras*, too imperfect to be determined, and a specimen of *Euomphalus*. Both of these are supposed to occur in the Auroral, which however has not yielded a single organic fossil in Northampton county. Overlying the Auroral, in these counties, Prof. Prime finds, at intervals, portions of an argillaceous limestone, containing in abundance the characteristic forms of the Trenton, such as *Chætetes lycoperdon*, and *Orthis pectinella*, with crinoidal stems. This limestone is said to differ from the Auroral in being "more compact, and not at all crystalline, and

of a gray-black color." It is described as "apparently conformable" with the Auroral, (Proc. Amer. Philos. Soc., Dec. 21, 1877).

§ 415. From his own observations in this region in 1875, the writer was led to believe that, besides the Auroral limestones, with their succeeding argillites, and the unconformably superimposed Silurian (Oneida) conglomerates of the North Mountain, there are, to the west of the Lehigh River, portions of two intermediate formations. One of these, marked by red-colored sandstones, conglomerates and slates, appears to be the same with the Upper Taconic or Cambrian belt, which has been traced by H. D. Rogers, Mather, Emmons, Logan and the writer, with some interruptions, from New Jersey to Canada, along the great Appalachian valley (§ 74, 93–96). The other is an impure black earthy limestone, becoming, in parts, a soft thinly-laminated flag-stone, which was seen lying, at moderate angles, above the blue limestone of the valley, not far from Copley, and was then supposed to belong to a different series. It is apparently the same with the Siluro-Cambrian (Trenton) beds, recognized by Prof. Prime in that vicinity.

§ 416. The evidences adduced in these pages furnish abundant proofs of the unconformable superposition of the Huronian to the Laurentian series, while the contrast between the highly disturbed condition and nearly vertical attitude of the former, and the broad folds and gentler dips of the Montalban, in so many regions, have long since been urged by the writer as evidences of a probable stratigraphical unconformity between the two. As regards the Taconian series, its apparent relations to the Montalban in Ontario, Maine, and North Carolina, and the frequent absence of the latter series where the Taconian rests unconformably upon Laurentian or Huronian, lead us to conclude to a want of conformity between Montalban and Taconian. In like manner, the absence of the Taconian at the base of the Cambrian, which, in so many places, reposes directly upon the Laurentian, or upon the Huronian, indicates a great stratigraphical break between Taconian and Cambrian.

§ 417. The evidence of various periods of disturbance,

marked by discordance, in the paleozoic strata along the Atlantic belt, have been pointed out in § 241, 242, where reasons are also given for believing in the existence of another such period between the Cambrian and the Siluro-Cambrian (Trenton-Loraine series). Mr. Murray's observations near Port-a-Port Bay, in Newfoundland, furnish a further proof of this. While the Cambrian rocks are there affected by sharp folds and great dislocations, he finds the limestones holding a Siluro-Cambrian fauna, near [illegible] to be "comparatively undisturbed," and concludes rightly, that the movement which brought the crystalline rocks into their position of apparently unconformable superposition to the former, was intermediate between the two periods named. While we dissent from his view of the origin of these crystalline rocks, and believe that the present geognostical relations are due to the disruption and uplifting of solid rocks of a more ancient system, rather than to an eruption of igneous matter, about "the age of the Chazy," the evidence, in either case, shows a period of great disturbance of the Cambrian strata in the interval above indicated, the natural result of which would be a want of conformity between these and the succeeding Siluro-Cambrian. § 377.

§ 418. Before passing to the consideration of the geology of Lake Superior, we may notice the presence of Huronian rocks in Newfoundland. In his report for 1868, Mr. Murray announced the existence of a series of highly contorted strata, overlying the Laurentian, and themselves overlaid unconformably by nearly horizontal sediments, the latter containing, in their lower portions, a Menevian fauna, and higher up, the forms of the Potsdam or Lingula flag-group. This intermediate series was declared to have close resemblances with the Huronian of the great lakes, to which it was at once referred by Mr. Murray. The name of Cambrian, which he at first used for this series, as synonymous with Huronian, he has since very properly rejected. (§ 359). According to Dr. Dawson, who has examined collections of these rocks, they are very similar to the Huronian of southern New Brunswick, so that we are constrained to look upon them as a portion of what has been called in

northwestern Newfoundland, the "altered Quebec group," which we have already referred to the Huronian series.

§ 419. This Huronian series, as described by Mr. Murray, is found in the southeastern part of Newfoundland, and makes up the chief part of the peninsula of Avalon. The strata are described as consisting, in the lower portions, of greenstones and slaty rocks, often epidotic and chloritic, with quartzites, conglomerates and jaspery petrosilex. These crystalline rocks have a thickness of many thousand feet, above which, in apparent conformity, are several thousand feet of sandstones and argillites, holding organic remains described as *Aspidella* and *Arenicolites*, the whole overlaid unconformably by the Menevian strata. (Report on the Geology of Newfoundland for 1868, page 12; Chem. and Geol. Essays, page 410, and Geol. Magazine for 1877, page 253).

As evidence of the great erosion to which this region was subjected in pre-Cambrian times, Murray notes that the nearly horizontal paleozoic strata above named are found extending alike over the outcrop of the Laurentian, and over the basal beds of the nearly vertical Huronian series.

§ 420. Huronian rocks were noticed in 1870, by Mr. Richardson, lying to the north of Lake St. John on the Saguenay, and near Lake Mistassini, where they occupy a considerable breadth, being underlaid by the Laurentian gneisses and limestones, and overlaid by the horizontal Silurian limestones which belong to the basin of Hudson's Bay. They present all the characters of the Green Mountain series. In 1872, Mr. Walter McOuat passed from Lake Temiscaming, on the Ottawa, northward to Lake Abbitibbe, over the height of land, and crossed a great area of similar rocks, described as closely resembling "the altered Quebec group" in eastern Canada, and as including diorites, with chloritic, micaceous and epidotic strata, roofing-slates, steatites, chromiferous serpentines, magnetite and copper ores. (Geol. Report for 1870, page 292, and for 1872, page 115).

§ 421. That these various areas of Huronian rocks, whether found in the Atlantic belt, or lying to the north and west

of it, formed parts of a great and widely-spread eozoic formation is clear, and it is a question whether portions of it may not exist in the Adirondack region. The writer has found in the drift, in the rear of Westport, in Essex county, New York, numerous fragments of Huronian schists, which may reasonably be supposed to have come from the mountainous region of the interior.

§ 422. In this connection it may be permitted to call attention to some notes by Major T. B. Brooks, published in 1872 (Amer. Jour. Sci. III, iv, 22) with the title, "On certain Lower Silurian Rocks in St. Lawrence county, New York, which are probably older than the Potsdam Sandstones." Under this head he has described certain strata found with the specular iron-ores of the Keene and Caledonia mines. Immediately under the ores, is said to be a considerable thickness of a greenish schistose magnesian rock, described as serpentine by Emmons, beneath which is a mass of crystalline limestone, several hundred feet thick, which, like the serpentine, is graphitic, and moreover contains crystals of bronze-colored mica. It includes in its lower part "irregular beds or veins of granite," and is underlaid by a well-characterized gneiss, with which it is conjectured to be unconformable.

Interposed in this limestone is a thin bed of sandstone, and a similar sandstone, sometimes conglomerate, and resembling the beds of the Potsdam, overlies the iron-ore. These strata, including the great mass of limestone, are thrown into folds with a northeast and southwest strike, and often dip at high angles. They have all the characters of the Grenville series of the Laurentian, from which there does not appear to be any good reason for separating them. The associated sandstone beds recall the similar case in Bastard, Ontario, described in § 286.

§ 423. As regards the newer series of crystalline rocks, found by Murray to overlie the ancient gneisses around Lakes Superior and Huron, we have seen that Logan, for a long time, maintained that they are the stratigraphical equivalents of the so-called Volcanic formations of Lake Superior, which are characterized by amygdaloids and sand-

stones, with native copper. In the *Esquisse Géologique*, in 1855, as well as in the geological map accompanying it, the two series are included under the common name of Huronian, then first used. A similar view was defended by Rivot and by Dawson, in 1856 and 1857, and the considerable mineralogical and lithological differences between the two groups were ascribed to the greater amount of alteration or metasomatic change which the former had undergone, (§ 141, 142, 152–157).

§ 424. In 1857, however, J. D. Whitney, while denying the distinction between the Huronian schists and the underlying gneisses, both of which he included under the common name of the Azoic system, declared the Volcanic or native-copper bearing group to be entirely distinct from the Azoic, and superior to it (§ 158–160). This latter conclusion was confirmed by the examinations of Murray in 1859, and 1860, (§ 162) and in 1863, in the Geology of Canada, the name of Huronian was confined to the crystalline schists which make the upper part of the Azoic system of Whitney, and, from their metalliferous character, were now sometimes designated the Lower Copper-bearing series. The Huronian, on Lake Superior, was now said to be "unconformably overlaid by a second series of copper-bearing rocks," which was the Volcanic formation containing native copper (loc. cit. page 67).

§ 425. As regards the age of this Upper Copper-bearing series, as it were now called by Logan, we have seen that Whitney declared that it "cannot be separated from the Potsdam sandstone with which it is associated." To this horizon he referred the nearly horizontal sandstones of the region, supposed to be the same with the red sandstones found at Sault Ste. Marie, and often called the St. Mary's sandstone. The observations of Mr. Murray in 1859, had however shown that these sandstones, to the southeast of Sault Ste. Marie, are overlaid, conformably, by a fossiliferous limestone belonging to the base of the Trenton, from which Logan concluded that "the underlying sandstones and other rocks constituting the Upper Copper-bearing series of Lake Superior, may thus represent the Chazy, Calciferous and

Potsdam formations, and be equivalent to the Quebec group, and the black slates and limestones beneath." This suggestion was put forth at the end of 1860, in a letter to Barrande, already cited (§ 201).

§ 426. A little later however, in Chapter V of the Geology of Canada, Logan gave reasons for believing that these sandstones, then regarded as of the age of the Chazy or St. Peter's sandstone (§ 273, 276), overlie unconformably the trappean and conglomerate rocks with which they had been united by Whitney, so that "the copper-bearing portions of the Lake Superior rocks might reasonably be considered to belong to the Calciferous and Potsdam formations" (loc. cit. page 86). Subsequently, in discussing the Quebec group, and the crystalline rocks of the Green Mountain range, then supposed to form a part of it, it was said: "This whole series of rocks however occupies a stratigraphical place which brings it to the horizon of the Upper Copper-bearing series of Lake Superior." (Ibid, page 236). In accordance with this conclusion, the Upper Copper-bearing rocks were, in the geological maps published by Logan in 1864, and in 1866, (§ 44), represented as belonging to the Quebec group, while the St. Mary's sandstone was referred to the Chazy formation.

§ 427. Reverting now to the more ancient rocks of this region, we have seen (§ 146) that Foster and Whitney recognized besides the Azoic schists, called by them Metamorphic, a great group of Igneous rocks, of different ages, in which were included granites, various greenstones and hornblende rocks, and the crystalline iron-ores. In this they were not singular, but in accordance with the generally received views of the time. Henry D. Rogers regarded the greenstones, epidotic rocks and serpentines of the Atlantic belt as igneous, and extended this view to the magnetic iron-ores, and even to the quartz veins of that region (§ 19, 30, 32, 37, 39). Emmons, in like manner, included the granite, hypersthene-rock, serpentine, limestones, and magnetic and specular oxyds of iron of northern New York, among the unstratified rocks of igneous origin, (§ 85–87) and Logan held the same view with regard to the Huronian

greenstones, (§ 141) although Rivot denied this, and asserted that they were altered sediments, a view which he extended to the traps of the Upper Copper-bearing series (§ 157).

§ 428. The arguments of Rivot, from the relations between the greenstones of the older series and their associated schistose rocks, (§ 152) were valid, and he erred only in considering them the stratigraphical equivalents of the granular traps and amygdaloids of the newer series. The studies of the writer in the years following, confirming such a conclusion, the indigenous character of these and similar greenstones, and other feldspathic rocks, was maintained by him in various publications, from 1858 (Chem. and Geol. Essays, pages 4, 33). This view is set forth at length in Chapters XIX and XX of the Geology of Canada, and further, in Contributions to Lithology (Amer. Jour. Sci. II, xxxviii, 253). The writer had already proposed to designate by the term *indigenous*, such crystalline rocks as have been formed *in sitû*, in contradistinction to those which have been intruded into their present places, and which were called *exotic*. The name of *endogenous* rocks was proposed for a third class of mineral masses, namely, the concretionary vein-stones.

§ 429. In 1865 appeared an important paper on the Iron Ores of Marquette, by Dr. J. P. Kimball (Amer. Jour. Sci. II, xxxix, 291) in which were set forth his studies in the Azoic system of Whitney, as seen in northern Michigan. He showed that the extensive belts or ranges, called plutonic granites by Foster and Whitney, and supposed by them to be more recent than the Azoic schists, were really indigenous gneissic rocks, belonging to an older series, which he pronounced Laurentian. As regards the overlying schists, he confirmed the judgment of Murray that they belong to the Huronian series, the greenstones and iron-ores of which were also declared to be not exotic but indigenous. Kimball, at the same time, pointed out the error of Rivot in uniting the Upper Copper-bearing series with the Huronian. He also recognized the existence, in the region, of eruptive granites and greenstones, as Murray had

already done in Canada, but declared that, though abundant in the Laurentian, they were very rare in the Huronian.

§ 430. In 1869, Dr. Hermann Credner published his studies of these same rocks in northern Michigan. He followed Kimball in admitting an older series of granitic gneiss—the Laurentian—which was unconformably overlaid by the Huronian rocks. These were described with much lithological detail, and with many sections, as a series of quartzites, limestones and red iron-ores, with argillaceous, chloritic and talcose slates, the latter two associated with diorites, which were declared to be not eruptive masses, but regularly interstratified members of the series. (Zeitschrift d. Deutschen geol. Gesellschaft, 1869). Credner estimated the total thickness of the series at about 20,000 feet, which agreed nearly with Murray's previous estimate of 18,000 feet, (Geol. of Canada, page 57).

§ 431. In 1869, Major T. B. Brooks, who had been associated with Prof. R. Pumpelly (with Credner as assistant,) in geological explorations in the northern peninsula of Michigan, commenced for the State, a systematic survey of that region. The results of their labors are set forth in the two octavo volumes of the Geological Survey of Michigan, published, with an atlas of maps, in 1873, in which the iron-bearing or Huronian rocks are described by Major Brooks, and the Upper Copper-bearing series by Prof. Pumpelly. In 1869 and 1870 large collections of rocks from the older series from Michigan, were by Prof. Winchell, then the director of the geological survey of that State, and by Major Brooks, placed in the writer's hands for examination, some of the results and conclusions of which are given in the following extracts from a letter addressed by him to Major Brooks, and dated Montreal, Feb. 22, 1871:

§ 432. "I find you are waiting for my conclusions, some of which are very interesting and important. You remark about the mica-schists, as being supposed by me wanting in the Huronian of Canada, and you send me specimens, Nos. 1215, b1154, b1153. I have for some time past recognized a Mica-schist series, which I suppose to overlie the Huronian, in fact the White Mountain series. * * * I was

therefore delighted to find in the specimens just named, well characterized White Mountain mica-schists, holding garnets, and well-defined crystals of staurolite, while the peculiar knotted mica-schist is not less characteristic. These rocks are abundantly spread to the north of Lake Superior, as last year's collections [of the Canada Survey] show me, and though I have been not able to fix their relations to the Huronian diorites, talcose schists, iron-ores, etc., I conclude from the facts seen near Portland, in Maine, and those described by Rogers, in Pennsylvania, that they are overlying rocks, and, in some cases at least, unconformably so. You say that they are *the youngest rocks in the region belonging to the Huronian.* I suspect that they belong to *a younger series.*" "I distinguish three crystalline gneissic series: I. Laurentian, (not to speak, for the present, of the Labradorian); II. Huronian; III. Terranovan [Montalban], these being respectively, in the United States, the rocks of the Adirondacks, the Green Mountains, and the White Mountains. I hope you will be able to decide whether there is any want of conformity between II and III. I should mention that in Hastings county, Ontario, the three series are all represented, and there is apparently a stratigraphical break between each."

"I have thus, I think, * * touched upon the principal points of interest in your collections, of which the two chief facts, are the close resemblance, and I believe identity, of the great iron-bearing dioritic, talcose series with the Green Mountain series, II, and the equally close resemblance of the rocks 1215 and 1151–1154, with the White Mountain series III, which I conceive to belong to a higher horizon."

§ 433. "The collections sent last * * * from Smith's Mountain and vicinity, are also members of what I regard as series III, and quite unlike the Huronian type, II." [Here followed details of thirty-nine specimens.] "Many of these rocks are very quartzose. Feldspar is occasionally developed, giving a gneiss which is seen in * * and * * in which the white cleavable orthoclase is developed so as to form a porphyritic gneiss."

§ 434. "A word about felsites. I have a large specimen

of conglomerate, with native copper, from the Albany & Boston Mining Co.'s property, brought me by Mr. Macfarlane, who has briefly described it in the Geological Report of Canada for 1863–66, page 156. The porphyry boulders and pebbles of which he there speaks, are fine examples of the felsite of which I wrote you, better named eurite or petrosilex, and passing into quartziferous porphyry. * * What is the source of the boulders? I suspect it will be found in the lower part of the Huronian system, for it has the typical character of the Huronian eurites, as seen along the east coast of New England, etc., from Rhode Island to Newfoundland, and also to the north of Lake Ontario. Do you know any such rock *in silû*, and have you perhaps deemed it eruptive?"

§ 435. The above conclusions as to this overlying gneiss and mica-schist series, was soon after made known by the writer, in his address in August, 1871, (§ 347), where it was said that the schists both of the Green Mountain and the White Mountain series "are represented in Michigan, as appears by the recent collections of Major Brooks * * kindly placed in my hands for examination. He informs me that these latter schists are the highest of the crystalline strata in the northern peninsula." (Chem. and Geol. Essays, page 274).

§ 436. The above collections were from the Marquette region, and the schists referred to the White Mountain series were designated by Brooks in his report, in 1873, as division No. XIX, described as "a formation of great extent and interest," "the youngest member of the series" of Huronian rocks, and "one of the thickest" in the upper peninsula of Michigan. It is often very silicious and micaceous, and contains besides black hornblende, staurolite and garnet, crystals of andalusite (loc. cit. pages 113, 130). In the same report, in the account of the Menomenee region in Michigan, was described (page 175) "a large outcrop of gneiss, with thin layers of granite," adjoining "a great hornblendic and mica-schist series," and presenting a Laurentian aspect, though "conformably overlying rocks unmistakably Huronian."

§ 437. In his subsequent examinations of the rocks of northern Wisconsin, to the south and west of the Menomonee river, Brooks found in the Penokie region a great area of similar gray gneisses, often granitoid, associated, as before, with hornblendic and mica-schists. These latter he regards as the equivalents of division XIX of the Marquette region, and at the same time suggests that some of the granitic rocks of the latter area may be identical with what he calls the Penokie granitoid formation. These later observations and comparisons, were set forth by Brooks in 1875, in a paper on The Youngest Huronian Rocks, etc. (Amer. Jour. Sci. III. xi, 206) under which head he includes the three areas of granitoid gneisses, with their associated hornblendic and micaceous schists. From their similar lithological characters, the entire absence from them of the iron-ores, which abound in what he calls the middle and lower portions of the Huronian, and from their geognostical relations alike to these and to the unconformably overlying Upper Copper-bearing series, Brooks concludes that the granitoid formation must be regarded as the youngest member of the Huronian series.

§ 438. It will be noticed that the immediate associate of this granitoid formation in each of the three districts is the peculiar micaceous and hornblendic schists, XIX, and it was these schists, and the granitoid gneisses, from the Marquette region, which the writer, so long ago as 1871, referred to the White Mountain or Montalban series, then, as now, placed by him above the Huronian—a testimony to the value of lithological characters in geology. In his paper already quoted, Brooks remarks on this point: "I would anticipate the objections which many will make to attaching much weight to lithological evidences in determining the age of formations one hundred miles apart, by repeating that the staurolitic mica-schist formation (XIX) maintains its mineralogical characters for over one half that distance." For further notices of these granitoid gneisses of the Montalban series, see Chem. and Geol. Essays, page 188, 244. These rocks have certain lithological resemblances to the gneisses of the Laurentian, but their inherent differ-

ences, not less than the character of the associated schists, suffice to distinguish them.

§ 439. The greenstones of the Huronian of Lake Superior, have been generally described as diorites, and the correctness of this designation is confirmed by the microscopic studies of Julien, and of Wright, who find them to be essentially composed of a triclinic feldspar and amphibole, (hornblende) frequently with chlorite. According to the former, some of them "may possibly contain pyroxene in place of amphibole." (Geol. of Michigan, 1873, II, 43).

§ 440. In the writer's account of the similar rocks from the Green Mountain range in Canada they were described as rocks composed in part of triclinic feldspars. "Through an admixture of hornblende, these feldspar-rocks pass into diorite, in different varieties of which the one or the other mineral predominates. * * * These compound rocks are often so finely granular as at first sight to appear homogeneous; at other times they are rather coarse-grained, and sometimes porphyritic from the presence of large crystals of feldspar. * * The imbedded hornblende-crystals are occasionally of considerable size, and dark-green in color. In some places, the hornblende is replaced by pyroxene or diallage."

After describing the relations between the steatites, diallage-rocks and serpentines, which often accompany these feldspathic rocks, it was said: "Both the serpentines and the diorites sometimes become schistose, and the latter seem to graduate into chloritic slates and epidosites, on the one hand, and into hornblende slates on the other, so that it is difficult to resist the conclusion that the whole series of rocks just named, from diorites, diallages, and serpentines, to talcs, chlorites and epidosites, have been formed under similar conditions." (Geology of Canada, pages 602, 612). See further, Amer. Jour. Sci. II, xxxvii. 266.

§ 441. A belt of Huronian rocks is found in southern Connecticut, to the west of New Haven. These were described by the late Prof. Silliman, more than half a century since, as "primitive greenstones," and later, by Percival, as a "chloritic formation." In 1876, J. D. Dana published

some notes on these rocks, describing the association of the greenstones with chloritic schists, and with serpentines, and adopting the previously announced conclusion of the writer, that "their common metamorphic origin cannot be questioned."

These rocks were at that time submitted to an examination by Mr. George W. Hawes, who found two of them to be identical in chemical composition, respectively, with an exotic dolerite and an exotic diabase, which, a few miles distant, in the vicinity of New Haven, break through the mesozoic sandstones. These exotic masses moreover closely resemble in aspect the indigenous rocks in question, which were accordingly described as aggregates of labradorite and pyroxene, (with some titanic iron) with the addition, in one variety, of a portion of chlorite (Amer. Jour. Sci. III, xi, 119 and 122).

§ 442. Dana, on account of this apparent identity in lithological characters, proposed to call these indigenous or metamorphic greenstones, metadolerite and metadiabase. Such a nomenclature is however based on a misconception of the province of lithology, which is distinct from that of geognosy. In the language of the author, in 1864, the same mineralogical aggregate "may occur both as an indigenous and an exotic rock, and different portions of the same mass may be seen, by different observers, under such unlike conditions that one may regard it as indigenous, and the other with equal reason, set it down as intrusive." "To the lithologist, who examines rocks without reference to their geological relations, the question of the exotic or indigenous character of a given rock is, in most cases, one altogether foreign, and one which can frequently be decided only by the geologist in the field." (Amer. Jour. Sci., II, xxxvii 254). These remarks remain essentially true today, especially for many granitic and euritic or petrosilicious masses, although the use of the microscope now enables one, in many cases, to distinguish between the indigenous rock and its exotic representative, as in the case of the diorites belonging to the two classes.

§ 443. It should be said that Mr. Hawes, by microscopic

examinations, has since found that the indigenous greenstones noticed by Dana, are really diorites, in one case containing some chlorite. (Ibid, III, xv., 219.) The further extended studies (as yet unpublished) by Mr. Hawes, of the Huronian greenstones of New Hampshire have yielded similar results, and show that these rocks, also, are essentially dioritic in character, consisting chiefly of an admixture of a plagioclase feldspar with hornblende, rarely containing grains of pyroxene, and often becoming chloritic, as long since described by the writer. From the similarity in chemical composition, and the intimate mineralogical relations between hornblende and pyroxene, it seems highly probable, that in accordance with the theory of exotic rocks maintained by the writer, (Chem. and Geol. Essays, 4, 9, 44), the exotic dolerites and diabases of the New Haven mesozoic are but displaced and modified greenstones of the underlying Huronian series.

§ 444. As regards the lithology of the Huronian of northern Michigan, it may be remarked that although Julien found no well-defined serpentines, the writer examined some years since, specimens of both massive and fibrous serpentine, believed to be from the falls of the Sturgeon river, received from Dr. Rominger of the Michigan geological survey, which had the characters of the typical serpentines of the Huronian of the Atlantic belt. Allusion should here be made to the serpentine of Presqu'isle, analyzed by Whitney. (Geol. of Lake Superior, II, 92). The writer has found some of the serpentine rocks of this region to be chromiferous.

It is of interest to note the occurrence of large quantities of a carbonaceous argillite, noticed by Brooks in several localities in the Huronian of Lake Superior, which has a black streak, burns white before the blow-pipe, and yields over twenty per cent. of carbon. (Geology of Michigan, I, part 1, 116).

§ 445. In the volume just quoted, the Upper Copper-bearing series was described as consisting of interbedded sandstones, conglomerates, melaphyres and amygdaloids, dipping northward at an angle of fifty degrees or more, and over-

laid unconformably by the nearly horizontal St. Mary's sandstones, in which Mr. Alex. Agassiz found, near Houghton, abundant pebbles of melaphyre and conglomerate, from the underlying series. No direct estimate of the volume of these latter rocks was attempted, though it was said "they have a thickness measured by miles, a thickness which they exhibit wherever they are known, at points hundreds of miles apart on the north and south shore" of Lake Superior. As regards the age of this Upper Copper-bearing series, it was, at this time, by Messrs. Brooks and Pumpelly, declared to have been "formed before the tilting of the Huronian beds, upon which it rests conformably," and to be probably more closely related in age to those, than to the overlying paleozoic sandstones. (Ibid. I, part 2, pages 1–6).

§ 446. The reader is now prepared to understand the significance of the question raised by the writer in 1871, as to the existence of the felsite or petrosilex-porphyries, in place, in the Lake Superior region; since these rocks, which had then been found by him to belong to the Huronian series, (§ 363–372), occur in pebbles in the conglomerates of the Upper Copper-bearing series, (§ 434). Besides the locality already mentioned, the great cupriferous bed of the Calumet and Hecla mine is a remarkable example of a rock made up almost wholly of the ruins of these peculiar petrosilexes. In 1872, as already described, (§ 372), he found these rocks, *in sitû*, on the north shore of Lake Superior, and was moreover led to suspect that both the banded jaspery quartzose porphyry of the Porcupine Mountains, described by Foster and Whitney as of igneous origin, (§ 151), and the similar rocks, said to occur at Mount Houghton in the southern range of Keweenaw Point, (§ 150); regarded by the same observers as an altered sandstone of the Upper Copper-bearing series, to which they referred this southern range, known as the Bohemian Mountains.

§ 447. The lithological characters of this southern belt, as already described, are however very like those of the Huronian, and widely different from those of the more northern belts, (§ 149) which are the typical Upper Copper-bearing rocks. This was noticed by Dr. Charles T. Jackson, who

remarked that the labradoritic greenstone of the southern portion, near Lake Labelle, differs from that of the northern ranges, in being a crystalline rock. He adds with regard to it: "If the rock were not connected with the more hornblendic traps, and in the same line of direction, bursting through the same kind of sandstone strata, I should feel disposed to regard it as of more ancient origin. Indeed, I am far from being satisfied that it is not more ancient, for the limited exposure of the rocks does not allow any geologist to be too confident as to its age." (Report to 31st Congress, 1849, Exec. Doc. No. I, part iii, page 473).

Mr. Ernest Gaujot, whose skill and long experience as a geological observer and a mining engineer, in this region, give much weight to his opinion, informs the writer that he has always believed the Bohemian Mountain range to belong to an older series than the copper-bearing rocks to the north of it.

§ 448. The reader who remembers that the Upper Copper-bearing series had already, in 1863, been declared by Logan to rest unconformably upon the Huronian, (§ 424) along the north shore of Lake Superior, might deem this an answer to the views of Brooks and Pumpelly, who, in 1873, still supposed the two conformable, and nearly related in age. As will be shown further on, however, the writer, from his studies on the north shore, in 1872, was led to conclude that the rocks there overlying the Huronian, of which they contain fragments, are not, as was supposed by Logan and by Murray, a lower division of the Upper Copper-bearing series, but belong to a distinct formation, of undetermined age. He, however, found that the conglomerates of the typical Upper Copper-bearing series at Mamainse include, as already described (§ 156), rounded masses of th[illegible] stones and chloritic schists of the Huronian, as we[illegible] characteristic gneisses and mica-schists of [illegible]an thus showing a stratigraphical break betwe[illegible]these c[illegible]stal line schists and the Upper Copper-bearing series; and confirming the conclusion already reached from the occurrence of petrosilexes, believed to be Huronian, in the conglomerates of the same horizon, in the Keweenaw peninsula.

§ 449. The great series of highly inclined sandstones and conglomerates which, with interstratified trappean masses, constitute the cupriferous formation of this region, and are clearly distinct both from the overlying sandstones and the underlying Huronian schists, required a distinguishing name. Hence, the writer, in his address on the Geognostical History of the Metals, before the American Institute of Mining Engineers, in February, 1873, designated it the Keweenaw group, and suggested that its included native copper had probably been derived from the oxydized and dissolved copper-sulphurets of the Huronian, (Trans. etc., I. 339, 341). In March 1875, Major Brooks, who had apparently overlooked the above announcement, but had himself, in the meantime, arrived at the conclusion that there exists a stratigraphical break, and a marked distinction, between the Huronian schists and the Upper-Copper-bearing group, declared that the latter constitute "a distinct and independent series, marking a definite geological period," and proposed for its designation the adjective Keweenawian. (Amer. Jour. Sci. III. xi, 210). For this, the writer, while recalling his own conclusions, and the name of Keweenaw series, given two years earlier, suggested the more euphonious word, Keweenian. (Harper's Annual Record, 1876, page xcv).

§ 450. Late researches in Wisconsin have thrown much additional light on the geology of the Lake Superior region, and the results are, in part, set forth in the volume on the geology of the State, published in 1877. The Primary or eozoic rocks of Wisconsin are, by Prof. Roland D. Irving, divided into an older gneissic, Laurentian, series, and an unconformably overlying series, regarded by him as Huronian, and including a great development of the petrosilex-porphyries. These latter have there been chiefly studied to the south of the great Primary area, in a region where numerous ridges of the underlying rocks appear through the horizontal paleozoic sandstones, "protruding, but not intruded," recalling the similar outcrops in southeastern Missouri (§ 373).

§ 451. These ridges, which are naturally the more resist-

ing portions of the eroded eozoic series, consist, in large part, of quartzites, massive and vitreous, or slaty, and interlaminated with soft aluminous schists, which have been called talcose. These various strata, which are highly inclined, and evidently belong to a series of great thickness, were, by Percival, called "altered Potsdam," and by Alexander Winchell, Lower Potsdam, but in 1862, were, by Prof. James Hall referred to the Huronian series, with which they are classed by Prof. Irving. The quartziferous porphyries, sometimes becoming schistose, and interbedded with unctuous schists, are found, either alone, or conformably succeeding the quartzites, the strata having a steep northward dip. In one section, on the Baraboo River, the total thickness of these rocks exposed is about 5,000 feet, including a breadth of about 600 feet of the porphyries, which, in another section, are estimated at not less than 3,200 feet in thickness. (Geology of Wisconsin, 1877, pages 501–521).

These rocks, from the lithological descriptions given, including the microscopic characters, and the results of chemical analysis, are evidently identical with the orthofelsites, or petrosilex-porphyries, previously described by the writer as characteristic of the Huronian series along the Atlantic coast, in the South Mountain in Pennsylvania, and in Missouri. They are the same with those which were discovered by him on the north shore of Lake Superior, and which enter so largely into the cupriferous conglomerates of the Keweenian series, on the south shore of the lake.

§ 452. The volume just cited does not give the late observations of Mr. E. T. Sweet of the geological survey of the State, which he has set forth in the Transactions of the Wisconsin Academy of Science for 1876, (pages 41–55), in a paper on the Geology of Northern Wisconsin. The Keweenian series, as was shown by Foster and Whitney, occupies a great synclinal on Lake Superior, which is traced uninterruptedly into Bayfield county, Wisconsin, a distance of more than two hundred miles, and with a thickness which, according to Mr. Sweet, is often over 60,000, and never less than 20,000 feet. Beyond this, it is followed, with some interruptions, for one hundred miles further to

the south-west, extending across the State of Wisconsin, and into Minnesota, though with a diminished volume, from the thinning-out of the conglomerates, and from erosion. The amygdaloids of this series are seen at the Dalles on the river St. Croix, where they yield native copper. These rocks, at this locality were, by Owen, regarded as eruptive, and newer than the adjacent sandstone, but Sweet makes it clear that, on the contrary, the lower beds of the sandstone rest horizontally upon the trappean rocks, and are made up in part of their ruins. These basal sandstones are shown, by the presence of *Lingulepis pinnæformis* and *Obolella polita*, to belong to the Potsdam sandstone of the region.

§ 453. These sandstones, with their interstratified and overlying magnesian limestones, constituting in this region a series of about 1,000 feet in thickness, beneath the St. Peter's or Chazy sandstone, have already been noticed, (§ 276–278) and are geographically distinct from the sandstones which, along the southern shore of Lake Superior, overlie unconformably the Keweenawian series. Mr. Sweet (loc. cit. page 49) remarks: "There is no known locality west of Keweenaw Point where the Lake Superior sandstone and the Potsdam of the Mississippi valley are not separated by many miles."

Under the name of Lake Superior sandstones, Mr. Sweet, following Dr. Rominger, includes the nearly horizontal sandstones which extend along the whole southern shore of the lake, including what has elsewhere been spoken of as the St. Mary's sandstone. This was, in 1863, regarded by Logan as probably of the age of the St. Peter's or Chazy sandstone of the Mississippi valley, (§ 165) and colored as such in the geological maps of 1864 and 1866 (§ 44).

§ 454. We have seen that Hall long since observed, in some beds between these sandstones and the overlying mass of Trenton limestone, strata containing organic remains of the Chazy formation. Dr. Rominger has since found, throughout the northern peninsula of Michigan, at this horizon, a series of beds, which, from their organic remains, he declares to represent both the Chazy, and the Calciferous formation,

of the New York series, leaving, according to him, no alternative but to regard the underlying sandstones as the equivalent of the Potsdam." (Geol. of Michigan, 1873, Vol. I, pages 71, 80).

These intermediate beds are partly calcareous or dolomitic, and partly silicious, consisting of "small perfect quartz crystals, with glistening facets, and sharp, unworn angles." Mixed with these, are numerous oölitic silicious globules, and, in some cases, masses of banded chalcedony, the whole recalling the observations made regarding the silicious beds of the Potsdam, in other localities (§ 269).

§ 455. These intermediate beds have a variable thickness, and in one case measure nearly one hundred feet. The thickness of the underlying sandstones, to the east of the copper-region, where they rest upon the older crystalline rocks, does not exceed three hundred feet, but to the westward, it is not easy to fix the limit between them and the older sandstones which form the upper portion of the Keweenian series, and are designated by Mr. Sweet as the Bad River sandstone. The upper portion of the Potsdam sandstone, in this region is, according to Rominger, light-colored and friable, the lower is dark-red or variegated, and, as shown by Mr. Sweet's analyses, contains a large proportion of clay and iron-oxyd, from the decay of the underlying Keweenian strata (Mem. Wisconsin Acad. 1876, page 50).

§ 456. The identity between the crystalline schists of Lake Superior (including those of northern Michigan and Wisconsin,) and those of the Atlantic belt, pointed out by the writer in 1870 and 1871, is admitted by Mr. Francis Bradley, who, however, still holds, as we have seen, (§ 404) to the notion of the paleozoic age of the latter. In an explanation of his geological map of the eastern half of the United States, published in 1876, Mr. Bradley writes: "The typical Huronian of Canada, according to description, occupies the position, and presents the lithological characters which we should naturally expect for the metamorphic portion of the adjoining Lower Silurian [Cambrian], corresponding precisely, in both aspects, with extensive beds of that age in the Appalachians. I have accordingly colored them Lower

Silurian." "Considerable portions of the so-called Archæan area, in Wisconsin and Michigan, have been shown by Brooks, Pumpelly and others, to be the equivalent of the Canada Huronian, for which reason they might with propriety be referred to the Silurian, but the data, as yet published, seemed so incomplete that the writer has preferred to leave them uncolored." Bradley further remarks, that after reaching the above conclusion with regard to the paleozoic age of the typical Huronian: "I learned through Mr. Selwyn, that Sir William Logan held the same view, for some time before his death" (Amer. Jour. Science III. xii, 287).

To this assertion, Mr. Selwyn replies in the same volume (page 461), as follows: "I am not aware that I ever mentioned Sir William Logan to Mr. Bradley, in the matter, and certainly, if Sir William held the views attributed to him, he never informed me of the fact." Mr. Selwyn further adds, with regard to the Huronian rocks: "We have not, so far as I know at present, any evidence which could warrant us in classing them with the Silurian." To the above declaration, the present writer must add his own testimony to the effect, that Sir William Logan, up to the last year of his life, admitted no such view as that attributed to him by Mr. Bradley.

§ 457. The above statements of Mr. Bradley called forth, in 1877, a note from Prof. Irving (Ibid. III, xiii, 308), who sums up as follows, "the facts proven, thus far, as to the older rock-series of Wisconsin." These are, first, the existence of an older gneissic and granitic series, the Laurentian; second, the unconformable superposition upon this of a second crystalline series, the Huronian, (in which is included the Penokie gneissic formation already mentioned); third, the superposition upon the Huronian, in probable unconformity, of the great Keweenian series, with a thickness of several miles; and fourth, the existence of a series of horizontal sandstones, resting unconformably upon the Keweenian, and holding the organic forms of the Potsdam sandstone.

Prof. Irving adds: "In order to include the Wisconsin

crystalline rocks within the Silurian, Mr. Bradley would have to stretch that term so as to cover three entirely distinct terranes, each overlying its predecessor unconformably, and many thousand feet in thickness; the highest of the three, in its turn, overlaid unconformably by horizontal sandstones with Primordial [Cambrian] fossils. As to any of the Wisconsin or Michigan rocks being altered equivalents of the Primordial, and newer strata, of the eastern States, such a hypothesis is certainly untenable for a moment." While conceding that such things may, as Bradley supposed, occur in the Appalachians, (a region with which Prof. Irving is unfamiliar) he says, "there has certainly been no period of metamorphism in the region of the northwestern States, since the beginning of the Primordial;"—a proposition which is equally true, in the writer's opinion, for the Atlantic belt.

§ 458. The Keweenian series has been shown to overlie unconformably the Huronian and Montalban schists, and to be, in turn, overlaid in like manner by the Lower Cambrian sandstones, thus occupying the same geological interval as the Lower Taconic or true Taconian series. With this, however, it has but very remote lithological resemblances, and, so far as known, nothing similar to the Keweenian series is found at this horizon, either on this continent or elsewhere. If, however, as seems probable in the present state of our knowledge, the greater part of this series is to be regarded, in opposition to the opinion of Rivot (§ 153)—as of volcanic origin, its lithological peculiarities are, in the nature of things, local, and have no chronological significance. We may recall, in this connection, the resemblances already noticed between the Keweenian series and the beds of amygdaloid and cupriferous conglomerate, apparently of the age of certain graptolitic shales, in the Upper Taconic rocks, in the province of Quebec (§ 185) and also the similar rocks of mesozoic age, in other regions. Charles T. Jackson, in 1849, argued from the lithological characters of the Keweenian series, that it was of the age of the New Red sandstone of Nova Scotia, Connecticut, Massachusetts, and New Jersey, and the same

view has been sustained by Marcou, and later, by Thomas Macfarlane and by Robert Bell. The valuable geological and lithological observations of Macfarlane, in this region, are set forth in the Canadian Naturalist, in 1868, (new series, vol. III.) where, on page 253, he has given his reasons for regarding the Keweenian rocks as of the age of the Rothliegende or Permian of Germany, which they closely resemble lithologically.

§ 459. The evidence since obtained from superposition, has however established their much greater antiquity, and confirms the opinion, that the composition of exotic rocks is in no way connected with the date of their extravasation. The conditions under which they have been ejected, whether as sub-aerial, sub-aqueous, or subterranean eruptions, and the consequently differing conditions of consolidation, must, however, necessarily modify greatly their mineralogical characters. It should moreover be considered, in comparing older with newer exotic rocks, that the deeply-seated portions of an erupted mass, which became solid under a vast pressure, and are now, in the case of older rocks, exposed by great subsequent erosion, must differ considerably in structure from the superficial and more-rapidly cooled portions of the same mass. Of such nature, for example, is the difference between granites and quartziferous trachytes.

§ 460. There are certain markings in the Keweenian rocks which are probably of organic origin. Logan, in 1847, described the occurrence in some of the earthy, or so-called tufaceous beds of the series, of numerous slender vertical tubes, filled with calcite, having a diameter of about a quarter of an inch, and a length, in some cases, of from eight to twelve inches. Two or more of these tubes were often found to coalesce, in ascending, (Geol. of Canada, page 71) and they were supposed by Logan to have been formed by currents of gas rising through a pasty mass. From the observations of the writer in 1872, on Michipicoten Island, where similar markings were found in an argillaceous stratum, he was led to compare them with some forms of so-called *Scolithus*, and to regard them as due to the burrowing of annelids. These were accompanied by large numbers

of two curious forms, the one club-shaped, and the other hemispherical, or dome-shaped, each recalling some sponges. These, like the tubes, were filled with calcite, agate or crystalline quartz, and sometimes in part with a greenish chloritic mineral, apparently delessite.

§ 461. The thickness of the Keweenian in the northeastern part of Lake Superior, as deduced from the observations of Macfarlane, is about 20,000 feet. The basal beds of the series are seen at Mamainse, and at Pointe aux Mines, to rest upon the Laurentian gneiss, fragments of which, and of Huronian greenstones, were noticed by Macfarlane in the conglomerates of the series. These rocks, it is to be observed, are what was called by Logan the upper division of the Upper Copper-bearing series.

§ 462. The rocks, regarded by Logan as forming the lower group or division of the Upper Copper-bearing series, are known along the northwest shore of Lake Superior, from Pigeon River to Thunder Bay, forming a belt on the mainland, and also the adjacent islands. The characters of these rocks are noticed in § 137, and they are described at some length in the Geology of Canada, pages 67–70. A further account of these, with some analyses, was given by Macfarlane in 1869, in a paper on the Geology of Wood's Location, (which includes Silver Islet,) (Can. Naturalist, new series, IV, pages 37–48 and 459–463). The dark bluish-gray slates were found to owe their color to carbonaceous matter, and the impure limestones of the series were dolomitic. The carbonaceous nature of this formation is further shown by the presence of an anthracitic substance, both disseminated, and filling small fissures in certain chalcedonic and flinty layers. (Geol. of Canada, page 68.) This series of nearly horizontal strata is traversed by dykes of dioritic rocks, which have been studied by Macfarlane, and both of these, in their turn, are cut by veins carrying native silver and various ores, in a gangue of quartz and calcite.

§ 463. The overlying rocks, according to the descriptions of Macfarlane, and the later observations of Prof. Robert Bell, given in the report of the Geological Survey for 1866–69, page 319, consist of red and white dolomitic sandstones

and shales, with interstratified reddish limestones, and variegated, yellow, red and greenish dolomitic marls, from which issue brine springs. This second group, as seen to the west of Black Bay, overlying the lower group of dark-colored carbonaceous strata, dips gently to the eastward, and has a thickness of 1370 feet. On the east side of Black Bay, appears a great series, estimated at from six to ten thousand feet in thickness, of sandstones and conglomerates, interstratified with trappean rocks, often amygdaloidal. Above all this, is a vast overflow of columnar doleritic rock, which, according to Bell, rests unconformably upon the various groups already described, including I, the lower dark-colored carbonaceous strata; II, the succeeding red and variegated sandstones, limestones and marls; and III, the conglomerates and amygdaloids. These three groups were, by Bell, supposed to form parts of the so-called Upper Copper-bearing series, which he, from the combined lithological resemblances, compared with "the rocks of Permian or Triassic age in Nova Scotia" (page 321). To this suggestion, Sir W. Logan replied in the same volume, (pages 472–475), pointing out the reasons for placing below the St. Mary's sandstone, the copper-bearing conglomerate and amygdaloids of the two sides of Lake Superior, of which group III, mentioned above, is supposed to form part.

§ 464. The strata of groups I and II were, by Logan, as by Bell, regarded as the lower members of one great conformable series, of which the amygdaloids and conglomerates form the upper part, but the writer, in 1872, found on the main land, not far from Silver Islet, in a conglomerate which forms the base of group II, pebbles clearly derived from the lower group. The latter, which presents at Thunder Cape a vertical section of 1300 feet of horizontal strata, is, moreover, entirely wanting a few miles to the eastward, in Black Bay, where, according to Logan, the red sandstones of II rest upon the Laurentian; a fact which suggests a want of conformity between the two sandstone groups.

§ 465. These relations were first described by the writer, in his address on the Geognostical Relations of the Metals, given before the American Institute of Mining Engineers, in

February, 1873, when the older group was noticed as "a series of dark-colored argillites and sandstones, which are as yet known only in this region, and are overlaid in slight discordance by red and white sandstones, apparently the same with those of the Keweenaw district, and the St. Mary's River. This older series, of Thunder Bay and its vicinity, which may be named the Animikie series, from the Indian name of the bay, is the lower division of the Upper Copper-bearing series of Logan. The great Keweenian group, with its cupriferous amygdaloids, is here absent, though met with a few miles further to the eastward." (Trans. Amer. Inst. Mining Engineers, I. 339.)

§ 466. In his explorations, in 1872, Prof. Bell found the nearly horizontal slates, sandstones and marls of group II, (whether with or without I, is not clearly stated) with the intersecting and overlying columnar trap, largely developed around Lake Nipigon, to the north of Lake Superior, and suggested for the whole Upper Copper-bearing series, (in which he included these horizontal strata) the name of the Nipigon group. (Report for 1872–73, page 106). In a further communication on the rocks of this region to the Institute of Mining Engineers, in May, 1873, the writer proposed to adopt this name of Nipigon for the red sandstones and marls of II, while retaining the name of Animikie for the lower group, I. (Trans., etc., II, 59).

§ 467. In the view of Logan, the Upper Copper-bearing series consisted, in ascending order, of I, the Animikie group; II, the Nipigon group, as above restricted, (neither of these being cupriferous), and III, the overlying cupriferous conglomerates and trappean rocks which we have named the Keweenian series. Macfarlane, on the other hand, regarded the Nipigon group as the equivalent of the horizontal sandstones which, elsewhere in the lake, overlie the Keweenian series. He had moreover previously noticed a series of bluish sandstones and slates, very unlike the red St. Mary's sandstones, overlying unconformably the basal beds of the Keweenian, where these rest upon the Laurentian, near Pointe aux Mines; and subsequently pointed out the close correspondence in structure, and in general

lithological characters, between these bluish overlying sandstones, and the lower or Animikie group of Thunder Bay. (Canadian Naturalist, new series, III, 252; IV, 38).

§ 468. In accordance with these facts, the Animikie and Nipigon groups are, by the writer, regarded as belonging to two distinct series, both younger than the Keweenian. The lithological characters of the Nipigon group are, moreover, very distinct from the Cambrian sandstones found at Sault Ste. Marie, and along the southern shore of Lake Superior, with which it was formerly confounded, and it will probably be found to belong to a more recent period; so that while the Keweenian series is pre-Cambrian, the Nipigon, and also the Animikie group, may be post-Cambrian, and perhaps mesozoic.

§ 469. The results of our studies of the older rocks of eastern North America, including the Lake Superior region, show the existence of the following series, constituting as many distinct terranes, the stratigraphical relations between which have already been pointed out (§ 416). These terranes are, in ascending order, as follows:

I. LAURENTIAN;—consisting of a lower division, the Ottawa gneiss, and an upper division, the Grenville series, between which is a supposed want of conformity. These two, together, constitute the Lower Laurentian of Logan.

II. NORIAN:—the Labradorian, or Upper Laurentian of Logan.

III. HURONIAN;—the Green Mountain series, or Altered Quebec group of Logan.

IV. MONTALBAN;—the White Mountain, or Mica-Schist series.

V. TACONIAN;—the Lower Taconic of Emmons, or the Hastings series, including a part of the Primal, Auroral, and Matinal divisions of Rogers; and constituting, with the Montalban, what was once called Terranovan by the writer.

VI. KEWEENIAN;—the Copper-bearing series of Lake Superior, found in the same geological interval as the Taconian, but not identified with it.

VII. CAMBRIAN;—the Lower and Middle Cambrian of Sedgwick, and the Lower and Upper Cambrian of Hicks; being the Upper Taconic of Emmons, and the Quebec group of Logan; or the Primordial Silurian, and part of the Lower Silurian, of Murchison.

VIII. SILURO-CAMBRIAN;—the Upper Cambrian of Sedgwick;—part of the Lower Silurian of Murchison, and the Matinal of Rogers, in part.

§ 470. The Cambrian sediments present, in the regions here considered, notable variations in volume and lithological characters, depending upon the sources from which they were derived. The Cambrian sandstones and dolomites of the Mississippi valley, and of the Ottawa basin, formed in proximity to areas of quartzo-feldspathic gneisses and petrosilexes, are very unlike their stratigraphical equivalents, the Upper Taconic or Quebec group, derived in large part from the ruins of the Huronian and Montalban schists, which formed the eastern shores of the Cambrian ocean. Those who have imagined these crystalline rocks to be the altered equivalents of the Cambrian sediments found along their northern and western borders, having unwittingly excluded the only reasonable explanation of the lithological peculiarities of these sediments. (§ 229 and § 404.)

471. "The distribution of the crystalline rocks of the Norian, Huronian and Montalban series, suggests the view that these are remaining portions of great, distinct and unconformable series, once widely spread over a more ancient floor of granitic gneiss of Laurentian age; but that the four series mentioned include the whole of the stratified formations of eastern North America, is by no means certain. How many formations may have been laid down over this region, and subsequently swept away, leaving only isolated fragments, we may never know; but it is probable that a careful study of the geology of New England, and the adjacent British provinces, may establish the existence of many more than the four series above enumerated." (Compare Trans. Amer. Inst. Mining Eng. I, 333, with Chem. and Geol. Essays, page 281). The importance of the Taconian, as a fifth series of crystalline rocks, distinct from the Montalban, was not at that time (1873) recognized by the author. It is not impossible that some of the sub-divisions of eozoic rocks described by Prof. C. H. Hitchcock, in his recently published Geology of New Hampshire, may be entitled to the rank of distinct series. A discussion of the

questions which arise in this connection would however require a space beyond the limits of the present history. (See, in this connection, Chem. and Geol. Essays, page 282.)

A similar remark must apply to the many valuable observations and generalizations made by Mr. W. O. Crosby, in his report on the Geological Map of Massachusetts, being a map sent by the Boston Society of Natural History to the Centennial Exhibition, in 1876. Mr. Crosby's report, and the added remarks of Prof. L. S. Burbank, are important contributions to the geology of eastern New England, and, like the more extended studies of Prof. Hitchcock, are, with some minor exceptions, in full accordance with the views already set forth by the writer in the preceding pages.

§ 472. The application of these distinctions, made in the east, to the crystalline rocks of the western part of the continent, is a task which is only begun. The late Mr. Marvine, in Hayden's report of geological explorations for 1873, compared the gneissic rocks of the Rocky Mountains, in Colorado, to the Laurentian. The writer, in a communication to the American Association for the Advancement of Science, in August 1877, confirmed this conclusion of Marvine's from his own observations near Fort Garland in the Sangre de Cristo range, and also in Glen Eyrie, in the Ute Pass, in Clear Creek Canion, and about Georgetown, in Colorado. "In all of the localities he found gneisses, often hornblendic, but scarcely micaceous, and in many cases in large masses, often granitic in aspect, with rarely interbedded gneissic layers. These strata are penetrated, in the neighborhood of Georgetown, by well-marked granitic masses, probably exotic. The red granitoid rocks, at and near Sherman, on the Union Pacific Railroad, are probably gneissic. These various rocks have all the lithological characters of the Laurentian, as displayed in the Laurentides, the Adirondacks, and the South Mountain between the Hudson and Schuylkill Rivers." "The gneissic rocks of the Wahsatch range, as seen in the Devil's Gate on the Weber River, are also Laurentian, to which are to be referred the similar stratified rocks found in the same range, further south, in the upper part of Little Cottonwood

Canion. Here, among loose blocks of the gneiss, were found occasional masses of coarsely crystalline limestone, with mica, and also varieties of pyroxenic rocks, characteristic of the Laurentian. At the lower part of the same canion, there are, however, well-marked eruptive granites."

§ 473. "The crystalline schists examined by the writer in the foot-hills, at the western base of the Sierras, in Amador, Placer, and Nevada counties, in California, have, according to him, all the characters of the Huronian series, as seen on the great lakes in eastern North America, and in the Alps. The auriferous quartz-veins, in the counties above named, are found traversing alike the crystalline schists, and the granites of the region, which are probably eruptive masses newer than the schists. To the Huronian, he also refers the similar crystalline rocks of the Coast range of California, as seen near San Francisco, and near San Jose." (Proc. Amer. Assoc., 1877, and also Proc. Bost. Soc. Nat. Hist. XIX. 276). Reference has already been made to the probable existence of Norian rocks in Wyoming, on the Laramie Plains (§ 315).

Since the publication of the above observations, the second volume of Mr. Clarence King's Survey of the Fortieth Parallel has appeared, in which Mr. S. F. Emmons supports the view of the Laurentian age of the gneisses of the Colorado range. Various observations in his report make it probable that other and newer eozoic terranes are represented in the vast Primary areas lying between this range and the Nevada basin.

§ 474. Allusion has been made above to the Huronian of the Alps, to which period Gastaldi has referred the great series of rocks, there known as the *pietri verdi*, or greenstones. These consist of dioritic and feldspathic rocks, (including the gabbros and euphotides), with serpentines, steatites, and chloritic, epidotic and quartzose schists, and have been regarded by most geologists as, in part, eruptive, and, in part, so-called contact-deposits, resulting from the action of erupted masses upon uncrystalline sedimentary strata. Such a hypothesis was, as we have seen, held by H. D. Rogers with regard to the similar rocks in Penn-

sylvania, and has lately been resuscitated for them, in Newfoundland, (§ 377–379). Nicholson, moreover, a few years since, applied a like view to the Huronian of Lake Superior, and recently George M. Dawson has expressed the opinion that rocks lithologically similar to these, in British Columbia, are of volcanic origin, and mesozoic in age.

§ 474. The greenstone group of the Alps has, like the similar rocks in North America, been, from its apparent stratigraphical relations in different localities, assigned to various ages, in paleozoic, mesozoic, and cenozoic time. The late researches in Alpine geology, of Favre, Gastaldi, and others, have however led to a different conclusion. According to the latter, the rocks of the greenstone group are not eruptive, but indigenous, and constitute a distinct stratified series, of great thickness, of beds and lenticular masses, in which the serpentines occupy a position near the base. These various rocks, he declares, belong to a constant and well-defined horizon, which is pre-paleozoic, and never make their appearance in other formations. This group has all the characters of the Huronian or Green-Mountain series, to which it has been referred by Gastaldi, and rests, probably unconformably, upon a great series of gneissic rocks, often porphyroid and granitoid, which include quartzites, graphite, and crystalline limestones, and are supposed by him to represent the Laurentian, of which they have the characteristics.

§ 475. The Huronian in northern Italy is followed by a great series of quartzites, with calcareous schists, micaceous limestones, and dolomites, including gypsums near the summit. These rocks, like the *pietri verdi*, have been, in turn, referred to various horizons from the Cretaceous to Lower Carboniferous, but according to Gastaldi, are of greater and uncertain antiquity. Their lithological characters, and their position, recall the Taconian of eastern North America. The three groups of crystalline strata above mentioned, are said by Gastaldi to constitute the basal rocks of Alps and the Appenines, and, overlaid in part by newer strata, may be followed from Mont Blanc to the Danube, the Adriatic, the Mediterranean, and the plains of

France. Gneisses and mica-schists, similar to those of the Montalban series, are also found in many parts of the Alps.

The reader may consult on this subject, two remarkable memoirs by Gastaldi, entitled, *Studii Geologice sulle Alpi Occidentali*, and the same, *parte seconda;* Firenze, 1871 and 1874, in quarto, with numerous maps and sections; also a letter by this geologist, entitled *Spaccato Geologice lungo le Valli Superiori del Po, etc.*, (*Bollctino del R. Comitato Geologico*, anno 1876, No. 3–4). See further, *Bul. Soc. Géol. de France*, 3me. série. I, 268, and on The Geology of the Alps, Chem. and Geol. Essays, pages 329–348. The views of Favre and Gastaldi, though still opposed by some of the older school of geologists, are in harmony with all the facts of American geology, as set forth in the preceding pages.

§ 476. For a study of the euphotides and gabbros of the Alps, in which the saussurite of the typical euphotide is shown to be not feldspathic, but epidotic; and for an extended comparison of these rocks with the related ones of the Huronian of the Atlantic belt, see the author's memoir on Euphotide and Saussurite, (Amer. Journal Science, II. xxvii., 336). For a similar study of serpentines, see his Contributions to the History of Ophiolites, (Ibid, II, xxv. 217, and xxvi. 234).

§ 477. Some further account of the Montalban rocks, and their included granitic veinstones, may be found in the author's Chemical and Geological Essays, pages 194–200. The relations there pointed out, on pages 192 and 208, between granitic, calcareous and metalliferous quartz veinstones, are well shown in Northbridge, near Worcester, Massachusetts, where the gray fine-grained gneisses of the Montalban series, dipping to the southeast, are traversed at right angles by several vertical parallel veins, which may be traced for considerable distances, and are ordinarily but a few inches in thickness. The veinstone in these is generally a vitreous quartz, which in some parts exhibits selvages, and in others, bands of white orthoclase, by an admixture of which it elsewhere passes into a well characterized granitic vein. The quartz veins, in places, hold cubic crys-

tals of pyrite, together with chalcopyrite and pyrrhotine, the latter in considerable masses, sometimes accompanied by crystals of greenish epidote, embedded in the quartz, and occasionally associated with red garnet. In one part, there is found enclosed in the wider part of a vein, between walls of vitreous quartz, a lenticular mass, three inches thick, of coarsely cleavable pink calcite, with imbedded grains of dark green amphibole, and, on one side, small crystals of olive-green epidote and red garnet; the whole mass closely resembling some crystalline limestones from the Laurentian.

§ 478. In the account previously given of the Huronian and Montalban rocks, as observed by Brooks to the south of Lake Superior, a notice of his latest publication on the subject, which appeared in September, 1876, (Amer. Jour. Science III, xii, page 194,) was inadvertently omitted. In the tabular view there printed, the crystalline rocks, by Brooks called Huronian, are divided into twenty groups. The granitoid gneisses, already referred to, (§ 436–438) as associated with the "great hornblendic and mica-schist series," XIX, previously regarded as forming the summit of the system, are now described as still newer than this, and are spoken of as "the youngest observed member, the granitic bed, XX,—only recently made out." It is these two divisions, XIX and XX, which the writer has already referred to the Montalban, and which, according to Brooks, occupy large areas both in the Menomenee and the Penokie regions.

§ 479. The observed thickness of the Huronian in this region, exclusive of the overlying gneissic series, is estimated by Brooks at not over 6000 feet for the Marquette district, and for those lying further west, on Black River, in Michigan, and where the Bad River crosses the Penokie range, in Wisconsin. To the south of Marquette, in the Menomenee district, it is said, the exposures may exceed 12,000 feet. We have however seen that in Wisconsin, according to Irving, the quartzites alone, of the Huronian, in one section, measure over 4000 feet, and the petrosilex-porphyries, in another, not less than 3200 feet (§ 451). If

these rocks be comprehended, the estimates of 18,000 and 20,000 feet of aggregate thickness, made by Murray, and by Credner, (§ 430) do not seem excessive. Although the petrosilexes were not noticed by the former, the presence of them, lately detected by the writer in the collections made by Murray, twenty years since on Lake Huron, show that these rocks were, by that observer, probably included under the head of cherts and jaspers.

The Huronian series in New Hampshire, excluding the petrosilex-porphyries, called by him Lower Huronian, (§ 371) is, according to C. H. Hitchcock, a little over 12,000 feet in thickness.

§ 480. The thickness of the Montalban, as seen throughout the Atlantic belt, appears to be very great. Hitchcock, in his Geology of New Hampshire, published in 1877, (Vol. II, page 674) includes under this name a series described as gneisses and feldspathic mica-schists, fibrolite-schists, and "Concord granites,"—the local designation of the fine-grained grayish micaceous gneisses of the Montalban. This series has, according to him, an aggregate thickness of 11,370 feet. Beneath this, he places 34,900 feet of rocks designated as Laurentian, of which however the upper portion, called the Lake gneiss, and estimated at 18,000 feet, is in the writer's opinion, probably, Montalban. Notwithstanding the apparent absence of the Huronian beneath the Montalban in the sections given by Hitchcock, the writer has already set forth his reasons for believing the latter to be the younger series. It is probable that a portion of the crystalline schists which, in certain sections, overlie, according to Hitchcock, the Huronian, may also belong to the Montalban terrane.

§ 481. As we have already seen, the hypothesis put forward by Mather, in 1843, that the whole of the crystalline rocks of western New England are but altered paleozoic strata of the Champlain division, (§ 81) has lately been revived by Prof. Bradley, who has extended it to the similar rocks of the Blue Ridge, and of the vicinity of Lake Superior (§ 404, 456). In a Handbook of Georgia, published by the Commissioner of Agriculture for that State, in

1876, and accompanied by a geological map, is a sketch of the geology of Georgia, which is understood to embody the opinions of Bradley with regard to the crystalline rocks of that State.

It is therein declared that Fulton county exhibits both "the Cincinnati gneisses," and "the reddish and gray hydro-mica schists, with some outcrops of the steatite and itacolumite, of Quebec age." In Habersham county, the rocks are referred to the same two divisions; those of the Blue Ridge proper, like those of the Chattahoochee Ridge, being said to consist of "hard hornblendic gneiss of Cincinnati age," while the softer schists of the intermediate valleys are supposed to belong to the Quebec period, (loc. cit., pages 40, 49, 59.)

§ 482. These same views are set forth, with further detail, in the explanations accompanying the catalogue of a collection of the rocks and minerals of Georgia, sent to the Paris exhibition of 1878; the catalogue having been prepared by Dr. George Little, the State geologist. It is therein said of the crystalline rocks of the State, that, although without fossils, they "apparently are all stratigraphical equivalents of the Lower Silurian;" in which however the only divisions recognized are the following, in ascending order: 1. Acadian or Lower Potsdam; 2. Upper Potsdam; 3. Quebec group, and 4. Cincinnati group. The thicknesses there severally assigned to these are given with a query.

The first, or Acadian, estimated at 13,000 feet, is said to consist of micaceous and hydro-micaceous schists, with bands of gneiss, having but little hornblende. It also includes roofing-slates. The second, or Upper Potsdam, of 2,000 feet, is made up of heavy-bedded gneisses, with little hornblende, as before, and with few schists. The third, or Quebec group, 12,000 feet thick, consists, in its lower part, chiefly of hydro-mica schists, with beds of hornblende-schist, gneiss, and quartzite, with much garnet, cyanite and rutile; and in its upper part includes limestone and dolomites, with beds of chrysolite-rock or dunite, associated with serpentine and other magnesian minerals, and with corundum. The fourth, or Cincinnati group, 15,000 feet thick, is chiefly

gneiss, in great part hornblendic, with but few hydro-mica schists. "It probably includes the flexible sandstones of the upper part of the Itacolumite series of Lieber," the lower part of which is said to be embraced in the Quebec group. All of these divisions are declared to be more or less auriferous, with the exception of the Acadian; but the rocks holding the chief part of the gold of the region are placed in the lower portion of the Quebec group.

§ 483. The writer has very recently had the advantage of examining, in some detail, the crystalline rocks of the region in question, in company with Dr. Little. The rocks of the so-called Cincinnati group, whether seen in the vicinity of Atlanta, Fulton county, at Mount Airy, Habersham county, or at various points intermediate, along the line of the connecting railway, are the characteristic hornblendic gneisses and mica-schists of the Montalban. The same is true of the greater part of the rocks exposed in the section from Mount Airy, by the base of Mount Yonah, to the Unaka Gap in the Blue Ridge, in White county; nor was there met with in this section across the whole mountain-belt anything representing the Huronian, or so-called altered Quebec group, as seen in the Green-Mountain range in Canada. In the valley on the northwest of the Chattahoochee Ridge, near Clarksville, in Habersham county, there were found outcrops of unctuous slates, which resemble those of the Taconian, and may be associated with the limestones, said by Prof. Bradley, to be quarried in the vicinity. The whole section, including the gold-bearing strata of the Nacoochee valley, bears a close resemblance to that already described across the same mountain-belt to the southeast of Roan Mountain, in North Carolina (§ 207.) Stone Mountain, near Atlanta, is a good example of the micaceous granitoid gneiss of the Montalban, so well known in New England;—the Concord granite of Hitchcock.

§ 484. The Montalban rocks throughout this region are, with local exceptions, (as in the mountain just named,) more or less completely decayed, often to a depth of fifty feet. The hornblendic gneisses, though still retaining considerable coherence, have lost the greater part of their

weight in the process; their specific gravity having been reduced from 2.97–3.08 to 1.20, and, for some varieties, to less than 1.00. These decayed hornblendic rocks, by the action of the weather, yield a strong red soil. The decayed mica-schists, which still retain their micaceous character, have there been called hydro-mica schists, though distinct from those of the Taconian, with which they have been confounded.

§ 485. The unerystalline formations of Cambrian and Siluro-Cambrian age, as displayed in northwestern Georgia, present, according to the catalogue just cited, the following characters. Above the Ocoee slates and conglomerates, which are of great but uncertain thickness, is found the Potsdam or Chilhowee sandstone, estimated at 2,000 feet, followed by the Knox group of limestones, sandstones and shales, (regarded as the representatives of the Calciferous sandrock and the Quebec group,) with an aggregate thickness of 4,400 feet. To these succeed the Chazy limestone, 600 feet; the Trenton limestones and shales, 700; and the Cincinnati group, consisting of silicious limestones and shales, with layers of red hematite, from 200 to 400; making in all about 8,000 feet of sedimentary strata from the base of the Potsdam. These, by the hypothesis of Prof. Bradley, become, in their extension a short distance to the southeastward, transformed into the 29,000 feet of crystalline rocks which he has referred to the Upper Potsdam, Quebec and Cincinnati groups; the intermediate divisions being no longer distinguishable.

§ 486. The arguments in favor of such a hypothesis, which have been urged by various writers on American geology since the times of H. D. Rogers and Mather, may be summed up under two heads: First, the apparent stratigraphical succession; and second, the supposed evidences of transition from the uncrystalline to the crystalline formations.

The mode of reasoning under the first, as applied to the rocks of the Atlantic belt, may be fairly stated to be as follows: Having assumed the possibility of such a transformation in lithological characters, and having taken for granted that the whole succession in question is a conform-

able one, without inversions or dislocations, a section is constructed from some formation in the paleozoic series, on the west side of the mountain-chain, and the crystalline rocks beneath which this formation appears to pass, to the eastward, are supposed to represent the succeeding members of the paleozoic series in question.

The radical faults in this reasoning are: First, that it overlooks the well-established fact that the prevailing structure in this mountain-chain is what may be described as a series of inverted folds, and of dislocations, as the result of which (at least in its western portions) the newer rocks dip, or seem to dip, eastward beneath the older ones; and second, that it assumes the point to be proved, namely: The possibility of the conversion of great masses of sandstone, limestone, and shale, into feldspathic, hornblendic and micaceous strata.

§ 487. The fallacies of the method are strikingly shown in its contradictory results, as illustrated by the different paleozoic horizons to which various theorists of this school have, in turn, assigned each terrane of the Atlantic belt. This has been abundantly shown in the preceding pages, for the Huronian and the Taconian. As regards to the Montalban, the characters of which are perfectly well-defined and persistent from New Brunswick to Alabama, we have seen that Messrs. Rogers, from a supposed parallelism with the paleozoic rocks of Pennsylvania, assigned the Montalban of the White Mountains to the lower half of the true Silurian, namely: the Oneida, Medina and Clinton formations of the New York series. Logan subsequently referred the same crystalline terrane to the Devonian period, having successively placed the Huronian in the Siluro-Cambrian, and in the Cambrian; while Bradley now makes the Montalban rocks to embrace both of these latter, leaving no place in his scheme for the Huronian.

§ 488. As regards the second argument, that from the imagined passage from crystalline to unerystalline rocks, we need only allude, in this place, to the existence of beds made up from the ruins of the former, which have been supposed to show the conversion of sedimentary into crystal-

line strata, instead of the reverse process. This point has already been illustrated in § 184 and § 413.

Distinct from such cases, are the statements of Mather, (§ 81) according to whom it is possible to trace, on the east side of the river Hudson, a gradual passage from the rocks of the Champlain division, across those of the Taconic series, to the crystalline schists of New England. This supposed transition was however based on the false assumption that the Siluro-Cambrian and the Cambrian or Upper Taconic of that region, are one and the same series, and that their apparent lithological differences are due to the commencement of a metamorphosis, which is still further seen in the marbles and schists of the Taconian, and reaches its highest point in the crystalline terranes further to the east. It will, however, be evident from what has gone before, that these different types of strata are not, as was imagined by Mather, the result of subsequent and unlike changes which one and the same uncrystalline paleozoic series has suffered in different geographical areas; but that, on the contrary, they belong to successive periods in paleozoic and eozoic time.

The great divisions of the latter, as set forth in § 469, present, in ascending order, a progressive change in mineral characters, the nature of which has been shown in § 405, 406; thus constituting a veritable passage, in time, from the granitoid Ottawa gneiss at the base of the Laurentian, through the intermediate Huronian and Montalban divisions, to the less markedly crystalline schists of the Taconian. The important question of the genesis of the crystalline rocks will be discussed in another place, but, in the mean time, an outline of the writer's views may be found in the preface to the second edition of his Chemical and Geological Essays, pages xxvii–xxxi.

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