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PRE-CAMBRIAN GEOLOGY OF NORTH AMERICA

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PRE-CAMBRIAN GEOLOGY OF NORTH AMERICA.[a]

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INTRODUCTION.

Our purpose is to give an account of the present state of knowledge of the general structure and correlation of the pre-Cambrian of North America. This book is not primarily a bibliography of pre-Cambrian literature, nor a petrography of the pre-Cambrian rocks, nor a treatment of metamorphism, nor an account of economic facts. Petrography, metamorphism, and economic geology are considered only so far as they have a direct bearing upon structural results, and then the substance of the established conclusions is given rather than the facts upon which they are based and the manner of reaching them.

The material contained in the volume consists of a general account of the pre-Cambrian rocks, a summary of all articles or parts of articles which have contributed knowledge upon the subject considered, summaries of the conclusions which appear to be established, and discussion of correlation of different regions.

In the summaries, so far as practicable, the original language of the author is used, although a single sentence of the summary may be taken from several sentences of the original. If the ideas can be conveyed in a briefer or clearer manner than the original language conveys them other words are used. No quotation marks are employed, for the ideas, whether in the original language or not, are wholly the ideas of the author whose book or paper is summarized—the whole is really quoted. It may be thought that better results would have been reached by indicating by quotation marks what words are taken from the original, but this method would have necessitated a constant and unpleasant alternation from quoted to nonquoted phrases, and would have made it much more difficult to convey briefly the thoughts of the original, for language adapted to a complete exposition is often not the best for a résumé.

The abstracts have the defects of all summaries—a certain amount of inaccuracy because all modifying and qualifying acts can not be

[a] This bulletin is a revised and enlarged edition of Bulletin No. 86, published in 1892.

given, and an undue amount of emphasis in the conclusions. In regions in which much work has been done these defects are not so serious as in little studied regions, for in the former the observations of independent observers confirm or neutralize one another. Into the summaries the editors enter only in so far that they must of necessity take what appears to them important and omit what appears unimportant. Undoubtedly in this respect many mistakes are made, and future investigations will show that omitted facts and conclusions have greater importance than now appears.

When the same writer repeats facts and conclusions in several articles summary is made of the most comprehensive article and references are made to the others in the footnotes. By giving the entire summary of the literature of one district before taking up another, epitomes of parts of a single paper are necessarily dissociated. By this method something of correlation is lost; but purely general work is summarized in the general chapter (Chapter I), and the subject of correlation is there treated.

References to literature are given at the ends of the chapters, the reference notes having continuous numbers. In the discussions closing sections or chapters and in the general chapter citations are not repeated. The original source of any statement attributed to an author may always be found by the aid of the index, where the name of each author is followed by references to the pages where his work is summarized.

In the discussion the aim has been not to call attention to all that seems to be erroneous, but first to point out where there is harmony between the different authors, often veiled because terms are used with different significations, and, second, to note the important conclusions which have been clearly determined. Statements and conclusions with which the writers do not agree are in general not criticised, nor is any refutation attempted, unless the point at issue is fundamental and can not be overlooked.

The map, like the summaries, is a résumé of the present imperfect knowledge.

The necessarily brief summaries will perhaps serve the purposes of those who are interested in the general stratigraphy of the pre-Cambrian. They will not answer for those who wish to understand in detail the structure of any given region. As the summaries are not made with reference to upholding any theory, they of necessity will fail to give all the facts which bear upon any particular hypothesis. But even for these special purposes it is hoped this volume may be found sufficiently full to be useful, and it certainly will be serviceable in directing students to the important literature.

The terms "system," "series," and "formation" are used with the stratigraphic significance given them in the report of the special committee of the United States Geological Survey on nomenclature and classification for the Geologic Atlas of the United States, published in the Twenty-fourth Annual Report, 1903. We shall speak of the Algonkian system, the Animikie group, the Negaunee formation. The Keweenawan series and the Huronian series collectively will be referred to as the Algonkian system.

Great difficulty has been encountered because of the unequal value of statements of fact by different men. Oftentimes we have found it impossible to discriminate surely between good and poor work because we were not familiar with the region described. In certain cases in which reports have read plausibly an examination of the purported facts in the field with the accounts in hand has shown the descriptive parts to be so inaccurate as to render the conclusions, while apparently well founded, wholly valueless. Facts and theories may be so inextricably mingled that no independent judgment can be reached as to the correctness of the conclusions, and often the facts of a report can not be used even by one personally familiar with the districts of which the report treats. The conclusions of another class of geologists are a series of guesses, which generally serve no purpose except that when any one of the numerous guesses has been established by the patient work of an investigator the conclusion is at once claimed as a prior discovery of the guesser. Sometimes the discoveries announced by a writer almost or quite simultaneously are wholly inconsistent with one another and with the facts which are described; for as with other men, so with geologists, many opinions are held at the same time which logically are exclusive of one another. Still another group of writers early reach a general theory as to the definite order of the evolution of the world. A person of this group year after year repeats the old statements and conclusions without any reference to the establishment of their falsity. More often than not he is one who has done little or no systematic detailed field work in any region. All facts and conclusions which bear in his direction are hailed as discoveries, while every adverse fact or conclusion is explained out of existence or dismissed as unworthy of consideration.

By following continuously the summaries of the writings of a geologist who has been long at work in a region it will generally not be difficult to get a fairly accurate idea of the value of the work done.

In many instances later work on the pre-Cambrian areas of North America has naturally been so much more full and accurate than earlier work that it raises the question whether the earlier work should be summarized in a book of this sort. Especially is this true where many of the rocks, early included in Archean or ancient metamorphic terranes, have subsequently been found to be Cambrian or later. In the present edition some of the summaries printed in Bulletin No. 86, which do not refer to pre-Cambrian rocks, have been condensed or omitted. They have been retained, however, if the rocks described are partly pre-Cambrian or, in a few cases, if the summary serves to bring out clearly the development of views of terranes early thought to be pre-Cambrian but later found to be wholly or in part post-Algonkian. In this way there is retained some that may seem useless, irrelevant, and overemphasized to anyone looking for the latest and best information on a pre-Cambrian area, and some that may seem useless even from a historical standpoint. We may have gone to an extreme in emphasizing the historical importance of early work, and the space given to the earlier work may be out of proportion to later and more accurate studies. In this we have followed our best judgment. In future editions of the pre-Cambrian correlation papers early summaries will necessarily be condensed to a greater extent in order to leave room for proper treatment of later work.

In the preparation of the first edition (Bulletin No. 86), the senior author visited most of the important areas of the pre-Cambrian of North America, and since its publication, in 1892, he has given considerable time to the study of the ancient crystalline rocks of the southern Appalachians and Piedmont, of Pennsylvania and Maryland, of New England, of the original Huronian and Lake Superior regions and their northward extensions, and of the Grand Canyon of Arizona and other districts of the Cordilleras. The junior author has studied principally the Lake Superior and Lake Huron regions and their extensions to the north, east, and west in Ontario. He has visited also pre-Cambrian areas in Nova Scotia, Newfoundland, New Brunswick, Arizona, Utah, Colorado, Wyoming, and Montana.

The present edition includes, in addition to the historical treatment, general summaries of the present state of knowledge of the geology of each of the principal pre-Cambrian areas, without special regard to the history of the development of this knowledge or of nomenclature. In case the published literature would not yield a satisfactory connected summary of the present state of knowledge regarding an area, this has been supplied by the authors, if they were sufficiently familiar with the ground, or by others who had especially studied these areas. Our acknowledgment and thanks are due to Messrs. Whitman Cross for a summary of the pre-Cambrian geology of Colorado, J. E. Spurr and Sydney H. Ball for the Georgetown (Colorado) quadrangle, Walter Harvey Weed for Montana, Waldemar Lindgren for Idaho, J. S. Diller for California, Arthur Keith and Thomas L. Watson for the southern Appalachians and Piedmont, Florence Bascom and E. B. Mathews for Pennsylvania and Maryland, George Otis Smith and William H. Hobbs for Massachusetts and Connecticut, A. C. Spencer for southeastern New York and New Jersey, G. B. Richardson for Texas, Samuel Weidman for central Wisconsin, Alfred H. Brooks for Alaska, John A. Dresser for the Eastern Townships, G. F. Matthew for New Brunswick, and Bailey Willis and Eliot Blackwelder for China. Our thanks are especially due to Mr. Ezequiel Ordonez for an excellent and comprehensive summary of the pre-Cambrian geology of Mexico. Finally we would acknowledge our indebtedness for valuable criticism to Messrs. Frank D. Adams for criticism of the section referring to the original Laurentian and Hastings districts, E. R. Faribault for southern Nova Scotia, Robert Bell and other members of the Canadian Survey for the northern interior of Canada, J. M. Boutwell for Utah, N. H. Darton and F. C. Calkins for Idaho and Montana, J. A. Taff for Indian Territory, Oklahoma, and Texas, F. L. Ransome for Arizona and Idaho, Waldemar Lindgren for New Mexico, and to others.

CHAPTER I.

GENERAL ACCOUNT OF THE PRE-CAMBRIAN ROCKS OF NORTH AMERICA.

DEFINITION OF PRE-CAMBRIAN.

The base of the Cambrian as defined by Walcott is marked by the beds known to contain *Olenellus* fauna or their equivalents. The pre-Cambrian as used in this bulletin includes all rocks below the *Olenellus* beds. For much of the continent an unconformity separates the *Olenellus* beds from underlying rocks; but in some parts of the continent the *Olenellus* beds appear to be continuous and conformable with underlying beds, some of which contain no fossils and some of which contain a few fragmentary fossils earlier than the *Olenellus*.

The discrimination and relations of the Cambrian and pre-Cambrian are discussed on subsequent pages.

MAJOR DISTRIBUTION AND STRUCTURE OF PRE-CAMBRIAN ROCKS.

It is convenient to think of the distribution of the pre-Cambrian rocks of North America as indicating the basal architectural features in the ground plan of the continent. The largest area of pre-Cambrian rocks of North America occupies the northeastern portion of the continent, extending northwest, north, and northeast from Great Bear Lake, Great Slave Lake, Athabaska Lake, Lake Winnipeg, the Great Lakes, and the St. Lawrence system to the Arctic and Atlantic oceans. This has been called the "pre-Cambrian shield," the "Laurentian continent," and the "Archean protaxis" of North America.

On the southeast the pre-Cambrian shield is separated by a narrow area of younger rocks from the pre-Cambrian rocks of the northern end of the Appalachian system or its northeastern extension. Beginning in Newfoundland and extending into Nova Scotia and New Brunswick and southern Quebec, through New England and thence down the eastern side of the Appalachian system in the mountains and in the Piedmont region to Alabama, are considerable areas of pre-Cambrian rocks which in part are not yet satisfactorily discriminated from crystalline rocks of later age. Detailed study of this region has continually reduced the estimated exposures of pre-Cambrian rocks. Also in eastern Canada and in the Adirondacks of New

York are outliers of pre-Cambrian rocks surrounded by younger sediments, which, while closely related in distribution to the Appalachian system, do not form any part of it. In western United States pre-Cambrian rocks form parts of some of the Cordilleran ranges, and in northern Montana and Idaho and in southern British Columbia they occupy very large areas.

In the Mississippi Valley isolated areas of pre-Cambrian rocks appear in Wisconsin, Minnesota, Iowa, Dakota, Missouri, Indian Territory, and Texas.

The general map (Pl. I) discloses an imperfect concentric grouping of the pre-Cambrian areas of North America, with the pre-Cambrian shield as the center. Similarly it has often been noted that the mountain folds of North America are roughly concentric with the pre-Cambrian shield. Within the pre-Cambrian shield itself there is a tendency for linear distribution of the pre-Cambrian subdivisions parallel to its borders, corresponding to axes of folding.

STATE OF KNOWLEDGE.

Of the great pre-Cambrian shield only the southern margin, bordering on the St. Lawrence and the Great Lakes, has been studied in detail. Because of the excellent and fresh exposures here developed by glacial erosion, because of the fullness of the pre-Cambrian succession, and finally because of the commercial value of the deposits of iron, copper, nickel, cobalt, and silver in the pre-Cambrian of the Lake Superior-Lake Huron region, the geology of the southern margin of the pre-Cambrian shield has become better known than that of most other pre-Cambrian areas of North America. Knowledge of this region is of special importance from the point of view of classification of the pre-Cambrian formations, since this region is the southern part of the great pre-Cambrian shield, and appears to exhibit all the elements of that shield. The area of the pre-Cambrian rocks for this immense region is vastly greater than for all of the remainder of North America, and the fullness of the record there exhibited, so far as yet known, is not surpassed elsewhere.

In Newfoundland, Nova Scotia, New Brunswick, and southern Quebec the mapping of the pre-Cambrian is sufficiently advanced to make possible a fairly definite statement of the general pre-Cambrian succession of the regions. For much of New England the pre-Cambrian rocks have not been discriminated from crystalline rocks of later age, and where they have been discriminated the details of the pre-Cambrian succession for large areas are not known. In a few areas, particularly in southern New England, the pre-Cambrian has been mapped in detail. If it is remembered that New England has been the home of many of America's leading geologists and has been studied continuously since geological study began in America, the extreme difficulty and complexity of New England geology may be realized.

In New York, Pennsylvania, New Jersey, and Maryland and adjacent parts of Virginia a greater proportional advance has been made. For most of this region the pre-Cambrian has been separated from the later rocks and the lithological relations have been determined. There is also partial agreement as to the succession and correlation of these units, but there remain important differences of opinion in these respects.

In the southern Piedmont region detailed work has been done in several areas aggregating 7,000 square miles, resulting in the separation of the pre-Cambrian units. Outside of these areas the great problem is still the separation of the pre-Cambrian from the later rocks. The extreme weathering is the principal obstacle in the way of geological mapping.

The isolated areas of the Mississippi Valley are all well known and for the most part adequately outlined.

The distribution of the pre-Cambrian rocks in the Rocky Mountain region is fairly well known, though there are areas now assigned to the pre-Cambrian which may be found to be of later age. Detailed studies of the pre-Cambrian of this region have been made in but few localities.

In the Great Basin region the crystalline axes of the mountain ranges were called pre-Cambrian to a large extent before their relations to the Cambrian were determined. To what extent these rocks are really pre-Cambrian and to what extent post-Cambrian is only partially known. There has been almost no detailed mapping of the pre-Cambrian rocks in this region.

In the Sierra Nevada, in the Coast Range, and in the Klamath Mountains the crystalline core rocks have been thought to be partly pre-Cambrian, but the next overlying rocks are so late in age and the region has been so deformed by late earth movements that a discrimination of the pre-Cambrian from later rocks is yet unsatisfactory. Almost nothing has been done in the way of the subdivision of the pre-Cambrian.

DISTINGUISHING FEATURES OF PRE-CAMBRIAN ROCKS.

There is difficulty in defining general distinguishing features of the pre-Cambrian rocks because they differ greatly among themselves. It will be seen later (pp. 19–25) that they may be naturally divided into two systems. The physical contrasts, from almost every point of view, between these two systems are in places greater than between the later system and the lower Paleozoic. Practically the only uniform distinction between the later system and the Paleozoic is the relative sparseness of fossils in the pre-Cambrian. As a whole, pre-Cambrian rocks are characterized by a relatively high degree of crystallinity and metamorphism, by a great abundance of igneous rocks, and by schists and gneisses of doubtful origin, in all of these respects differing in general from the post-Cambrian rocks. Locally in the Appalachians, where the post-Cambrian rocks have been closely folded and intruded with great masses of igneous rocks, they have been so metamorphosed that their discrimination from the pre-Cambrian rocks is extremely difficult. On the other hand, in the Lake Superior region certain of the later pre-Cambrian rocks have been so little metamorphosed that they resemble the unmetamorphosed Cambrian sediments of this region, and geologists have differed as to whether they should be correlated with the Cambrian or the pre-Cambrian. In various parts of the Cordilleras igneous rocks of post-Cambrian age are so abundant that pre-Cambrian age may not be premised for a series predominantly igneous. The reverse of this appears in the Lake Superior region. Distinct fossils, while lacking in the pre-Cambrian of most areas, are found in at least two pre-Cambrian areas of the United States. The pre-Cambrian of the great shield is separated from later rocks by a great unconformity. This is true for other pre-Cambrian areas, but not for all. In the Appalachian and Piedmont regions the known Cambrian grades down into the Ocoee group, here assigned in part to the pre-Cambrian. In northwestern United States and adjacent parts of British Columbia the Belt series and its equivalents are separated from the Cambrian by an inconspicuous erosion interval, and in places seem to grade directly into the Cambrian.

The pre-Cambrian rocks illustrate all processes of metamorphism, including katamorphism and anamorphism. Indeed, so largely are they altered that the study of pre-Cambrian geology involves a study of the principles of metamorphism. Especially well shown are the changes which accompany the development of schistose structures under deep-seated conditions. The exposures of the pre-Cambrian of northern North America have been so stripped of their weathered products by glaciation that excellent opportunities are afforded for studying deeper-seated alterations.

SUBDIVISION OF THE PRE-CAMBRIAN.

THE DUAL CLASSIFICATION.

The United States Geological Survey has since 1889 recognized a dual division of the pre-Cambrian into Archean and Algonkian.[a]

[a] Tenth Ann. Rept. (for 1888–89) U. S. Geol. Survey, 1890, p. 66; also Twenty-fourth Ann. Rept. (for 1902–3) U. S. Geol. Survey, 1903, p. 26.

The senior author has favored the term Proterozoic (earlier life) as the era equivalent of the Algonkian. His proposed classification of the pre-Cambrian as given in the first edition of this bulletin (Bulletin No. 86) and repeated in the Sixteenth Annual Report of the United States Geological Survey, except that "Agnotozoic" is omitted, reads as follows:[a]

Era or group.	Period or system.
Paleozoic	Cambrian and others.
Agnotozoic or Proterozoic	Algonkian.
Archean	Archean.

When it was proposed to use "Agnotozoic" or Proterozoic as the equivalent of Algonkian it was not known that the Archean contained sediments.

A few fossils had been found in Algonkian rocks. Thus there was a certain basis for using the term Proterozoic as equivalent to Algonkian. But carbonaceous shales, limestones, and iron formation rocks extend to the very bottom of the known geological column, suggesting existence of life in the earliest rocks. However, the life remains of the pre-Cambrian are far too scant to warrant any attempt at subdivision of the pre-Cambrian on the "zoic" basis. The major classification of the pre-Cambrian has been made upon a physical and not a paleontological basis. For this reason, therefore, the writers prefer to use the terms Archean and Algonkian, without separate "zoic" equivalents.

Our proposed classification of the pre-Cambrian is as follows:

Algonkian	One or more series in various geological provinces, separated by unconformities. To these series local names are applicable.
Unconformity.	
Archean	Keewatin. Eruptive unconformity. Laurentian.

Chamberlin and Salisbury,[b] in their text-book of geology, have proposed the divisions Proterozoic and Archæozoic for the rocks which we here call Algonkian and Archean, but such "zoic" division is not founded on evidence furnished by fossils and represents a hope of the future rather than achieved results. It seems probable from the great physical contrasts in the Archean and Algonkian that this proposed "zoic" division would be justified if we could know the life of these two eras, though this is yet a speculative belief based upon general principles.

[a] Sixteenth Ann. Rept. (for 1894–95) U. S. Geol. Survey, pt. 1, 1896, p. 762.

[b] Chamberlin, T. C., and Salisbury, R. D., Text-book of geology, vol. 2, 1906, pp. 133–217

Émile Haug,[a] realizing the difficulty of dividing the pre-Cambrian on the "zoic" basis, has proposed to use only a single "zoic" term for all of the pre-Cambrian rocks. For this term he has chosen the word "Agnotozoic," which he separates into Archean and Algonkian. If Professor Haug's plan be followed, it seems to us that the preferable term for this place is Proterozoic rather than "Agnotozoic."

However, since the proper choice of "zoic" terms can be made only by future development of knowledge, and there is no consensus of opinion on the matter, we shall avoid introducing the "zoic" nomenclature into this discussion, confining ourselves, as has been said, for the major subdivisions of the pre-Cambrian to the terms Algonkian and Archean, the forms of which correspond with the physical basis upon which the separation is actually made.

It does not follow from emphasis on structural and physical characteristics rather than paleontological differences that this classification has any less value than at later periods. As Chamberlin expresses it:[b]

> The groups Paleozoic, Mesozoic, and Cenozoic are not, in the conception of some of us, defined by a distinct kind of life, as in the case of some of the minor horizons, for the life fits better the idea of a gradation than of a distinct separation. These great divisions are rather, as I see it, at least, great historic movements fundamentally dependent upon dynamic events, than paleontological divisions. Originally they were supposed to be separated by universal catastrophies to life, and their distinctness was due rather to the intervention of the catastrophe than to the different quality of the life, which is merely seized upon as a characteristic suited to nomenclature.

In this sense the Algonkian system is characterized by essentially the same criteria as the Paleozoic and the Mesozoic.

The Algonkian includes the major part of the pre-Cambrian sedimentary rocks—practically all to which ordinary stratigraphic methods may apply—though it also contains sediments so deformed and metamorphosed that their stratigraphy can not be deciphered. The Archean is the basement complex, perhaps including several series or groups, upon which the Algonkian rests, so far as known, with unconformity. It includes massive igneous rocks, acidic and basic, crystalline schists and gneisses derived from them, large masses of schists and gneisses of unknown origin, and relatively small masses and shreds of fragmental formations so highly metamorphosed and so closely associated with the schists and gneisses in structure and age that they can not yet be practicably separated in mapping.

The Algonkian is characterized by well-assorted fragmental and chemical sediments giving evidence of extensive decomposition of land areas and of the passage of normal cycles of erosion. Igneous rocks are abundantly present, but for the most part are subordinate

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[a] Traité de Géologie, I, Les Phénomènes géologiques, Paris, 1907, p. 22.

[b] Personal communication, January 6, 1908.

in amount to the sediments. The Archean is characterized mainly by igneous rocks, with the sediments in very small quantity. The Archean sediments, moreover, are frequently of "wacke" type, and, so far as known, are not largely of the cleanly assorted kinds resulting from complete decomposition, as in the Algonkian. The differences between the Archean and the Algonkian may even express themselves in topographic contrasts. For instance, in the Lake Superior region a peneplain on the Archean has most irregular minor variations on the surface, while the same peneplain crossing the Algonkian rocks is characterized by linear and somewhat regular features. In the preparation of the final Lake Superior report a physiographic study of the region resulted in subdivision into physiographic provinces which were found to correspond essentially with the division into Archean and Algonkian.

The Archean rocks are highly folded, contorted, mashed, and metamorphosed and usually contain secondary structures. Also the older of them have been intruded again and again by plutonic igneous rocks on a scale not equaled in the rocks of any other period. Thus the Archean presents intricacy of structure and metamorphism not paralleled by any other system of rocks. The Algonkian rocks also have been extensively folded, metamorphosed, and intruded by igneous rocks, but in these respects are less intricate in their structures than are the Archean rocks. It follows from these differences that to the Algonkian rocks ordinary stratigraphic methods can be usually made to apply, as in the Paleozoic, whereas in the Archean there has been little progress in stratigraphy. In addition to the above points of difference it has been found that in general there is a great unconformity at the top of the Archean. This immense unconformity, strongly marked by basal conglomerates, explains the contrasting points in lithological character, amount of deformation, intricacy of intrusion, and degree of metamorphism of the two systems of rocks. So striking are the differences between the two systems in lithology, structure, and metamorphism that in field study and mapping a broad dual classification is naturally made, regardless of the significance of such classification or theories of origin. This practical distinction has been recognized by many workers who have given much time to mapping the pre-Cambrian formations, from the days of Logan to the present time. In the Marquette district of Michigan, for illustration, this classification was made from the first by a number of geologists, although under different names and with different interpretations. We believe it is not going too far to state that usually where the pre-Cambrian succession has been fully worked out, in an area where it is reasonably full and well exposed, enough criteria for the separation have been found to make the dual classification into systems corresponding to Archean and Algonkian a natural and convenient one for purposes of description and mapping.

The above statements in reference to the Archean differ from those in the previous correlation bulletin (No. 86) in that the presence of sedimentary rocks in the Archean is now definitely recognized. It was never held that sedimentary rocks did not exist in the Archean, for the possibility of sedimentary origin of some of the doubtful Archean rocks was repeatedly mentioned, but emphasis was placed on the fact that the rocks then assigned to the Archean were igneous so far as their origin was recognized. This became then one of the common criteria for the separation of the Archean from the Algonkian. But it should be remembered that this was only one of the criteria used and that the general contrasts in lithology, structure, and metamorphism, together with the magnitude of the unconformity separating them, were given equal weight. The discovery of definitely recognizable sediments in the Archean now requires that less emphasis be laid upon sedimentary origin as a criterion for separating the Algonkian from the Archean, although the criterion still remains an important one; for the Algonkian rocks, as already indicated, are characterized by well-assorted sediments, to many of which ordinary stratigraphic methods apply, while the Archean is not so characterized. The assignment of sedimentary rocks to the Archean does not in the least affect the other important criteria for the discrimination of the Algonkian and the Archean.

The recognition of sediments in the Archean has naturally led to some confusion where undue emphasis has been placed on sedimentary origin as a criterion for the separation of the Algonkian from the Archean. This is one of the easiest criteria to apply and has been seized upon and made the one criterion in districts where structural and metamorphic discrimination has not been made or is not possible.

Our development of knowledge may be summed up in the statement that the broad dual classification into Archean and Algonkian was based on a considerable number of factors; that one of these factors has been found to be less conclusive as a means of discrimination than previously thought, although still important; that the remaining factors have the same weight as formerly; and that the classification into Archean and Algonkian is as fundamental as before thought. The classification was proposed as a working, not as a theoretical, classification. With advance of knowledge, modification of our understanding of its significance was to have been expected, and may be expected in the future. Sederholm [a] aptly expresses the situation when he writes:

> I think we have warnings enough from the prior history of the geology of the oldest sediments. Many times when geologists have succeeded in subdividing

[a] Personal letter.

the basement of the oldest clastic formations, then recognized as such, they have begun with separating a younger clastic series from a new basement complex, older than that which bore that name before. In the beginning, no opinion has been expressed as to the question whether this complex contains clastics or not. But after a time this practical division made in the field has been confounded with the theoretical one, the "basal plane" of life is thought to lie at the bottom of the clastic series, and the basal complex is unduly regarded as Azoic.

Chamberlin and Salisbury[a] state that the mode of derivation is perhaps the most important distinction between the Algonkian as a whole and the Archean.

The Algonkian sediments were produced by mature decomposition of older rocks, and this implies that they were not derived by rapid mechanical abrasion, such as that which accompanies and follows great elevation and excessive precipitation. The great series of quartzites were derived from the complete decomposition of quartz-bearing rocks, and involved the almost complete separation of the quartz grains from other constituents, while the thick beds of shale arose from the complementary clayey products of decomposition, from which most of the basic oxides had been removed by carbonation. It is scarcely too much to say that the material of the larger part of these great series first became soils on the surface of the parent areas, and were only removed at a rate that permitted the renewal of the soil beneath as fast as it was washed away above.

They believe that the Archean sediments contrast with Algonkian sediments in being the results of immature decomposition. This suggestion is a most interesting one and may afford a new line of attack on the problems of the subdivision of the pre-Cambrian.

DIFFICULTIES IN LOCAL USE OF CLASSIFICATION.

It has been urged that even if it be desirable to use general terms like Archean and Algonkian for certain regions, there are other regions where such classification is unnecessary, undesirable, and misleading in that it implies a correlation which is not warranted; that the terms Algonkian and Archean are really local terms and should not be used in general classification. It is agreed that there are pre-Cambrian successions in which the known facts do not now seem to warrant this dual subdivision of the pre-Cambrian. But the difficulties of applying this classification locally should not stand in the way of classifying our knowledge of the districts in which it does apply, which, as a matter of fact, include the vast regions of pre-Cambrian in which are the fullest and best-known pre-Cambrian successions in the world. Even in post-Algonkian fossil-bearing rocks it is frequently impossible to carry the same classification, even as to systems, from one region to another, and when the classification is carried over it seldom has precisely the same significance lithologically, stratigraphically, and chronologically. Yet if the classi-

[a] Text-book of geology, vol. 2, 1906, pp. 199–200.

fication is based on the largest number of essential factors common to many districts, it is of value as an aid in grasping the essential points in similarity of geology and serves as a standard for the measurement and expression of local variations. In some regions it is difficult, indeed impossible, to place the dividing plane between the Cambrian and the Ordovician. For instance, in the eastern United States it has been found so impracticable to do this that a great limestone formation is known as the Cambro-Ordovician limestone. In various regions it is difficult to place the plane between the Paleozoic and the Mesozoic, and elsewhere between the Mesozoic and the Cenozoic. The same is true also of the Cambrian and the pre-Cambrian. For instance, although it is easily possible to place the boundary between the Paleozoic and the pre-Cambrian in Montana, yet in the area along the international boundary and to the north in Canada it is extremely difficult to make this division, and the discrimination has not yet been made. These difficulties in making discriminations locally between geological divisions which are generally recognized are especially likely to be found where there is continuity in the sediments of different periods, where fossils are absent or have been obliterated, where there has been strong metamorphism, and where great igneous intrusions have taken place.

The fact of the matter is that geological classification must be made up from regions where the relations are known rather than from regions where the relations are not known. To follow any other method than this would hopelessly bar geological progress. As has been pointed out, in the great area of the pre-Cambrian shield of Canada, which should give the basis for the division of the pre-Cambrian rocks of North America, it has been practicable, wherever close studies have been made, to separate the Archean and the Algonkian. The same has been equally true in the great pre-Cambrian area of northern Europe, including Scotland, Scandinavia, and Finland, and also in China.

It is therefore certain that the discrimination between the Archean and the Algonkian is one of fundamental importance in the vast areas of pre-Cambrian which should give the basis for classification. In some outlying areas, where it is not practicable or advisable in the present state of knowledge to make the division between Archean and Algonkian, the rocks may be called pre-Cambrian. In this matter we follow well-known procedure. For instance, in various regions all the rocks antedating the Mesozoic are so complexly intermingled and so difficult to discriminate that they are called simply pre-Mesozoic, leaving to the future the separation of the different units of the basement complex, which may include all rocks antedating the Mesozoic. Many other illustrations of the same principle could be given.

ARCHEAN SYSTEM.

The Archean system is a crystalline complex beneath the base of the determined sedimentary succession. Dana, followed by the Canadian and other geologists, used the term "Archean" in the sense of pre-Cambrian. It is still so used by the geologists of the Canadian and some other surveys. The United States Geological Survey has restricted the term to a complex of basic and acidic surface and deep-seated igneous rocks, of schists and gneisses in part derived from them and in part of unknown origin, and of shreds and small masses of metamorphosed sediments, all unconformably below and older than the Algonkian sedimentary rocks, which are the lowest series in which ordinary stratigraphic methods have been applied. Their lithological variations are many. The common kinds are granites, micaceous, hornblendic, chloritic, and quartzose schists and gneisses, metabasalt, metadiabase, and metagabbro. The sedimentary rocks include slate, graywacke, conglomerate, tuffs, iron formation, and marble. The Archean as a whole is homogeneous in its heterogeneity. Its characteristic, though not universal, structure is cleavage or schistosity, often much folded and contorted. It frequently possesses also a banded structure, sometimes developed with the cleavage during rock flowage and sometimes due to minute parallel igneous intrusions parallel to the schistose layers.

SUBDIVISION OF ARCHEAN SYSTEM.

To the present time the subdivisions of the Archean system are mainly those of igneous succession rather than those of sedimentary stratigraphy, although in two or three districts there has been an attempt to apply sedimentary stratigraphy to relatively small areas.

In the Lake Superior-Lake Huron part of the pre-Cambrian shield of the Archean it has been possible to divide the rocks into two series. The older series of the Archean has been called the Keewatin. This division of the Archean consists largely of various greenstones and green schists, which, where not greatly metamorphosed, show the structures and textures of volcanics. In other words, the most characteristic and extensive class of rocks of the Keewatin is a surface material. A very common feature of these volcanics is a peculiar ellipsoidal structure which has been fully described by Clements and others. With these igneous rocks are subordinate amounts of iron-bearing formation and slate. Prior to 1905 the Keewatin had been called the "Mareniscan" by the senior author, but he now follows the recommendation of the joint committee of Canadian and United States geologists that Keewatin be used because of its prior use by Lawson for the series as typically exposed in the

Lake of the Woods district, but only later defined by the above-mentioned committee in the broad sense used in this volume.

The second division of the Archean, the Laurentian, consists of granite, granitoid gneiss, gneiss, and acid schists, characterized by red or light colors. Wherever this series comes into contact with the Keewatin the rocks of the Laurentian are found to be intrusive into the Keewatin. In general the intrusions occurred under deep-seated conditions.

Thus the separation between the two great divisions of the Archean is upon the basis of age, but with this go further contrasts as to volcanic and plutonic characters and contrasts in lithology and color, in general the Keewatin being composed of intermediate or basic rocks, while the Laurentian is mainly composed of acidic rocks.

In the Lake Superior part of the pre-Cambrian shield the closest studies have been made of the relations of the Laurentian and Keewatin, and in a number of areas there has been an attempt to separate the sedimentary portion of the Keewatin from its volcanic portion. For instance, in the Keewatin of the Vermilion district the larger masses of the iron formation have been separated from the metabasalts and schists in the mapping, and evidence is offered to show that the iron formation is, at least in part, stratigraphically above the associated greenstones. In the Laurentian of the same district several igneous masses have been discriminated and their relative ages determined. In the Marquette district the Keewatin has been subdivided into the Mona schist and the Kitchi schist, and the Laurentian is also subdivided. Notwithstanding the success in subdividing the Archean into formations upon a lithological basis in certain of the Lake Superior districts, the fact remains that for the Lake Superior region as a whole vastly more remains to be done than has been accomplished.

This same division of the Archean into Keewatin and Laurentian, which prevails in the Lake Superior region, has been found by us to apply to the great region north of Lake Huron.

Miller has also found this broad subdivision into Keewatin and Laurentian to apply in eastern Ontario and western Quebec. Miller and Knight have recently concluded that part of the Grenville rocks of the Hastings district are similar to the Keewatin in lithology and relations and are to be correlated with it. The problem of correlation of the Grenville as a whole is still unsolved.

We believe, from field observation and from a study of the literature, that the classification may apply somewhat generally in eastern Canada and Newfoundland.

It thus appears that the division of the Archean into Keewatin and Laurentian applies for the greater area extending from the west end of the Lake of the Woods at least to the eastern part of Ontario, a distance of 700 miles. While the great northern extension of this shield has not been studied in such detail as to enable the geologists who have traversed it at intervals wide apart to map the Keewatin and Laurentian separately, those who are familiar with the southern part of the area of the pre-Cambrian shield do not doubt that this discrimination can be carried out when detailed mapping is undertaken for this vast region.

In this pre-Cambrian shield, in addition to the granites, gneisses, and schists which antedate the Algonkian, there are later igneous rocks which intrude the Algonkian. For great areas where reconnaissance work has been done the granites and gneisses of the Archean have not been discriminated from those intrusive into the Algonkian, but both have been mapped under the designation "Laurentian." This practice has been necessary because of the difficulty of making discriminations for the immense areas of crystalline rocks accessible only by arduous travel by canoe. In recognition of this situation, the international geological committee in 1905, while defining Laurentian as above stated, recommended that its use be also permitted, preferably with an explanatory clause, for broad areas of granites and gneisses where the masses of different ages have not been discriminated. This recognizes the present usage of "Laurentian" on many of the Canadian maps, but should not be construed as an approval of the view that this "Laurentian" as a whole is intrusive into the Algonkian. A considerable part of the rocks mapped as "Laurentian" is intrusive into the Algonkian, but another large part is intrusive only into the Keewatin. "Laurentian," as used in the broad sense, becomes a catch-all for pre-Cambrian gneisses and granites of any area where structural relations have not been discriminated. There is danger that unless the narrower and much more desirable application of the term recommended by the committee be emphasized the discrimination of Archean and Algonkian granites, so important for structural purposes, will be overlooked. This has been one of the most fruitful sources of controversy in the mapping of the pre-Cambrian to the present time. It is obvious that statements concerning the relations of the "Laurentian" in the broader sense can not have the same significance as those relating to the Laurentian as limited by the international committee.

A similar dual classification of the Archean has been made by Keith in the southern Appalachians and Piedmont, where an ancient gneiss series is intruded by granites. There is little evidence upon which to base a correlation of this Archean or its subdivisions with that of the pre-Cambrian shield.

For other areas of pre-Cambrian little has been done toward the subdivision of the Archean.

It is possible—indeed probable—that some of the rocks which in the eastern part of the United States and in the Cordilleras have been referred to the Archean will in the future be ascertained to be Algonkian. It has already been pointed out that in a given area, until it can be ascertained whether a group of pre-Cambrian rocks is Archean or Algonkian, the general term pre-Cambrian may wisely be used.

ORIGIN OF THE ARCHEAN.

The lithological complexity of the Archean is such that no generalized statement can be made to cover the origin of all its rocks.

Rocks in accord with Hutton's law that the present is the key to the past.—The abundant igneous rocks and the schists and gneisses clearly recognized as their altered equivalents are not different from igneous rocks of later age, except perhaps in amount of metamorphism shown in many localities, and hence so far as these rocks are concerned a discussion of the origin of the Archean would involve a discussion of the origin of igneous rocks in general. The small amounts of sedimentary rocks and schists and gneisses known to be their altered equivalents are also not different in kind, though differing in relative proportions of kinds, in total amount, and in metamorphism, from sedimentary rocks of Algonkian and later eras. The oldest known Archean rocks, the Keewatin of Lake Superior and eastern Canada, come under the classes of rocks definitely recognizable as of igneous and sedimentary origins. Some of the oldest pre-Cambrian rocks have been regarded as sedimentary in the Piedmont area from Pennsylvania southward into the Carolinas, and in the Georgetown district of Colorado. It is of interest to note also that the earliest sediments and gneisses of the Lewisian in Scotland are in places so intimately associated as to suggest that the gneisses may be intrusive into the sediments, which would make the sedimentary rocks the oldest in the region. Sederholm finds sedimentary rocks well toward the base of the pre-Cambrian of Finland and believes that certain earlier gneisses will prove to be sediments.

But the Archean contains in addition large masses of gneisses and schists whose origin has not been proved. They are essentially the same as gneisses and schists which have been shown to result from the metamorphism either of igneous or of sedimentary rocks, and it is probable that a part of them, an unknown proportion, are so derived. That any of them represent rocks of different origin, possibly the so-called original crust of the earth or its downward crystallization, necessary to the nebular hypothesis of the origin of the earth, there is yet no positive evidence to show, but the existence of such rocks is possible. It has been held that the granites and gneisses of the Laurentian have resulted from the subcrustal fusion of igneous or sedimentary rocks when buried under great thickness of later rocks, and that, after having undergone subcrustal fusion, they have invaded the overlying rocks and thus may have served as the basement upon which the overlying rocks were deposited, notwithstanding the fact that they now show intrusive relations to the overlying rocks. Such intrusive rocks, whatever their ultimate source, are igneous at the point of intrusion, and thus the subject of subcrustal fusion becomes one of the origin of igneous rocks, which need for our purposes be only incidentally referred to. The particular evidence brought forward that some of the Archean igneous rocks have resulted from fusion of sediments is: (1) Observed gradation between igneous rocks and sediments; (2) composition of the igneous rocks influenced by the digestion of the adjacent sedimentary rocks; (3) density stratification of the digested rock resulting in differentiation, thus perhaps causing the part of the igneous mass in contact with the given sedimentary to have a different composition from that required by the digestion of the adjacent sediments; and finally, (4) broad field relations, as for instance where great oval areas of granite bulge up through limestone or other formations, as in the Hastings and original Laurentian districts. In limited areas evidence of subcrustal fusion seems to be reasonably conclusive, but to the present time the quantity of material which has been proved to be of this origin is insignificant as compared with the masses of igneous rocks in the Archean. In the nature of things, conclusive evidence could scarcely be expected throughout these masses. That subcrustal fusion has taken place upon such a scale as to account for any large part of the Laurentian is yet unproved.

Departure from uniformitarianism.—When we consider the relative proportions of rocks of igneous and sedimentary origin the Archean does represent a departure from the uniformity of conditions of later geological time. Igneous rocks make up by far the greater part of the Archean. The Archean was essentially a period of world-wide volcanism. Sedimentary rocks are relatively insignificant. The sediments may have been more abundant in upper horizons of the Archean than in lower, and have been largely removed by erosion. Sedimentary rocks may have been metamorphosed beyond recognition into gneisses and schists. To some extent this is doubtless true, but even if a considerable part of the schists and gneisses of unknown origin were found ultimately to be sedimentary the sedimentary part of the Archean would still be subordinate to the igneous part.

So far as present evidence of the relative importance of sediments and igneous rocks in the Archean is concerned, the known facts do not contradict Chamberlin's hypothesis of the development of the earth by solid meteoric accretion. On this hypothesis the earth must have reached a sufficient mass to hold at least the beginnings of a hydrosphere in which sedimentary rocks could be deposited at a period long antedating that of the formation of the Archean rocks which now appear at the surface. If erosion were to cut much deeper into the Archean it might still show shreds of sedimentary rocks, which might decrease in quantity the further erosion continued. On this hypothesis also the earlier rocks should be less well assorted than the later ones. As already noted, Chamberlin and Salisbury contrast the little-assorted "wacke" type of the Archean and later systems.

Cleavage and gneissose structure in the Archean and crustal shortening.—One of the most conspicuous features of the Archean rocks is the prevalence of banded, gneissose, and schistose structures over very large areas. That these structures are in some part developed by a secondary mechanical action admits of no doubt. It seems to be likely, however, that certain of the gneissose and banded structures were developed before the masses had finally cooled. Sederholm thinks he has shown this conclusively for certain of the Finnish rocks. If the structures are secondary it is certain that some of the rocks have been under such extreme conditions of pressure and temperature as practically to be brought again into the plastic state. That the Archean rocks should show more secondary deformation than the later ones is to be expected from their greater age. Most theories of crustal deformation postulate a shearing or tangential movement of a rigid outer crust over a liquid, plastic, or semiplastic interior. The observed facts in the field suggest the existence of such a slip zone. Van Hise has suggested that the slipping below a rigid crust is due to the fact that the movement here is by rock flowage, which seems to require less energy than deformation by rock fracture, which the upper rigid zone must suffer. Van Hise has further suggested that the eastward dip characteristic of many of the Archean areas of North America may have been developed during a westward slipping of the crust under tidal stresses. Chamberlin has suggested that if the sea beds represent areas of sunken wedges or blocks of the earth, and the continent the projecting wedges or blocks, there should be a thrust developed near their contact such as to produce a cleavage dipping toward the continental areas and away from the sea.

The large amount of folding and cleavage in the Archean has been taken to imply a much larger amount of crustal shortening for this period than has occurred in any subsequent period. It is difficult to make any quantitative estimate because all later deformations have affected the Archean, because the cleavage may indicate in part tangential shearing of an outer over an inner shell, as described above, rather than crustal shortening, and because the vast masses of igneous intrusions of the pre-Cambrian occupy space compensated by the folded and schistose rocks surrounding them. While the folding and cleavage of the Archean represent a considerable amount of crustal shortening which took place before the deposition of the Algonkian and later rocks, there is not sufficient evidence to show that this shortening before Algonkian time was greater than that during later periods of equal length.

Conclusion concerning origin of Archean.—The rocks of the Archean include (1) dominantly plutonic and surface igneous rocks, (2) small masses of sediments, (3) considerable masses of schists and gneisses clearly derived from secondary alteration of the igneous and sedimentary rocks, (4) very subordinate amounts of gneisses resulting from subcrustal fusion of sediments, and (5) other schists and gneisses of unknown origin.

In the Lake Superior region and over large areas in Canada the oldest determinable rocks of the Archean are dominantly surface volcanics, with which are very subordinate amounts of sediments. In these ancient rocks there have been intruded plutonic igneous rocks upon a great scale.

ALGONKIAN SYSTEM.

The Algonkian system, as this term is used by the United States Geological Survey, includes sedimentary formations and their metamorphosed equivalents with associated igneous rocks beneath the Cambrian and resting upon the Archean complex. It includes the greater part of the sedimentary rocks of pre-Cambrian age and practically all to which present stratigraphic methods have been found to apply, though it contains also sedimentary rocks so deformed and metamorphosed that their stratigraphy is obscure. The sedimentary rocks not included are those in small quantities so intimately associated with the rocks of the Archean unconformably below that their stratigraphic relations to the adjacent rocks are not fully known. The Algonkian sediments are known to contain a few fossils, representing the earliest forms of life yet found. No indisputable fossils have been found in the sediments of the Archean below.

EXTENT AND SUBDIVISION OF THE ALGONKIAN.

In the Lake Superior region, where the Algonkian system is developed in fullest succession, it may be subdivided on the basis of unconformity into four groups, each consisting of several formations. North of Lake Huron three Algonkian groups are known. In other areas the divisions are fewer. Part of the Hastings and Grenville rocks of eastern Ontario and western Quebec are probably Algonkian, but their stratigraphy and correlation are not yet solved. The largest area of Algonkian known is that of the Belt series of northern Montana, Idaho, and southern British Columbia. The Belt series is subdivided lithologically into a number of formations, but represents practically continuous deposition. To the south in Montana the Cherry Creek sedimentary rocks are assigned to the Algonkian. While their relations to the Belt series are not shown by direct contact, the relatively greater metamorphism and deformation of the Cherry Creek group indicate its earlier age and probable separation by unconformity. The quartzites of the Uinta and Wasatch mountains, correlated with the Belt series, are essentially structural units. The same is true of the quartzites and slates of Needle Mountains, Colorado. In the Grand Canyon of the Colorado there are two groups classed in the Algonkian, separated from each other by a minor unconformity.

The vast quantities of intrusives and igneous rocks in the Algonkian are given the names of the series which they intrude or are interbedded with, provided it can not be shown that they are of later age. Thus granites intrusive into the Algonkian but not into later systems are Algonkian granites. This differs from the method of some geologists of the Canadian Survey, who have commonly called such granites "Laurentian," but this method is now discontinued by the Canadian Survey so far as practicable.

FOSSILS IN THE ALGONKIAN.

Fossils are very rare in the Algonkian system. From several localities discoveries of fossil forms have been reported, but, with two exceptions, these are held by Walcott to be inorganic or doubtfully organic. The two exceptions are the fossils in the Belt series of Montana and those in the Chuar group of the Grand Canyon series, both of them referred to the Algonkian. In the Belt series the fossils thus far found occur in the Greyson shale, at a horizon approximately 7,700 feet beneath the summit of the Belt series at its maximum development. The fauna includes four species of annelid trails and a variety that appears to have been made by a minute mollusk or crustacean. There also occur in the same shales thousands of fragments of one or more genera of crustaceans, some of them of considerable size. Crustaceans were found also by Weller in the same series in the lowest limestone exposed in the Rocky Mountain front, near the forty-ninth parallel. The fossils of the pre-Cambrian Grand Canyon series are a small discinoid shell found in the upper division of the Chuar group and a Stromatopora-like form from the upper portion of the lower division and the central portion of the upper division of the Chuar. Other obscure forms appear whose identification is doubtful.

Additional evidence of life in the Algonkian is the existence of carbonaceous shales, slates, and schists. Limestone and iron-bearing formations may point in the same direction. Still another doubtful bit of evidence bearing toward the existence of life is the fact that the Algonkian sediments derived from the Archean are the result of mature decomposition, which is held by Chamberlin and Salisbury [a] to imply the agency of vegetation.

The progress of paleontological knowledge has been downward. Before there was a recognized Cambrian there was a well-defined Silurian, and it is possible that when all parts of the world become geologically known other faunas will be discovered below the Cambrian as distinctive in character as the Cambrian is from the Silurian, though this is no longer held probable by geologists best qualified to judge. The first traces of such life have already been found, as above noted, and the great areas of Algonkian sediments not differing essentially from post-Cambrian sediments afford an inviting field for further search for fossils. It is widely agreed that beds containing the *Olenellus* fauna shall be taken as the base of the Cambrian. This fauna is abundant and varied. It includes all the stems of the animal kingdom except the vertebrate. Some biologists say that nine-tenths of the differentiation had taken place at the beginning of Cambrian time, implying a prior life of vast duration.

Beneath the *Olenellus* horizon the lack of fossils is striking, even where there is no unconformity separating the *Olenellus* horizon from the underlying sediments, and these sediments are of such a nature as to indicate that the waters in which they were laid down were as satisfactory for supporting life at the beginning as at the end of the enormous lapse of time which they represent, and all the conditions have since been favorable for the preservation and discovery of fossils. This great contrast in fossil content signifies an important change of conditions, the precise nature of which does not yet appear. W. K. Brooks developed the hypothesis that the late Algonkian oceans contained all the fundamental types of animals, but with soft bodies, and that these did not begin to secrete hard parts until early Cambrian time. Upon reaching or "discovering" the shore, there began a rapid development and struggle for existence, which required the development of hard parts, giving rise to the fossil forms now found in the Cambrian. Daly varies this hypothesis by suggesting that the amount of lime and magnesia necessary for the hard parts of animals was not present in the ocean until late pre-Cambrian time; that prior to this time all the lime and magnesia was deposited through the medium of organic ammonium carbonate, leav-

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[a] Text-book of geology, vol. 2, 1906, p. 139.

ing none for the animals; that the great addition of lime and magnesia, giving excess over that deposited by the ammonium carbonate, was due to orogenic movements, followed by base-leveling near the close of the pre-Cambrian. Daly also concludes from compilation of available analyses of pre-Cambrian carbonate formations that magnesia was relatively more abundant in the pre-Cambian than it has been later. Biologists now emphasize the deleterious effects of magnesia upon life. It is possible that these facts are to be correlated. Lane[a] has argued that the pre-Cambrian ocean was of different composition from that of to-day, and that this difference in composition had an effect on the development and preservation of life.

Whatever the real significance of the contrast in fossil content between Cambrian and pre-Cambrian rocks, it stands as a fact which must be clearly recognized and which seems to prevent the certain classification of nonfossiliferous continuous downward extensions of the *Olenellus* horizon with the Cambrian or Paleozoic.

LENGTH OF ALGONKIAN TIME.

The highly developed life records of the Cambrian, together with the thickness of the pre-Cambrian and the existence of several important unconformities between its members, indicate an enormous lapse of time for the Algonkian. If time can be measured by thickness of sediments, the Algonkian was perhaps as long as or longer than all Paleozoic time, and Algonkian and Archean time together may have been longer than all post-Algonkian time. Indeed, if the amount of life development be the standard by which to measure time, the appearance of the Cambrian fauna at the base of the Paleozoic may be a comparatively modern event.

DEFORMATION AND METAMORPHISM OF THE ALGONKIAN.

Algonkian rocks have, on the whole, suffered more deformation and metamorphism than younger rocks. Deformation has expressed itself in folding, faulting, jointing, and irregular fracturing. In conjunction with these structures metamorphism and cleavage have so frequently developed as to be common features. In the amount of structural deformation and attendant phenomena there is great difference between the members of the Algonkian system, even in the same district, and a vast difference in different geological provinces. On the whole, the phenomena of deformation and metamorphism are greater than in the Paleozoic. But the difference between the Algonkian and the Paleozoic in these respects is no greater than the difference between the Paleozoic and the Mesozoic. The contrasts in deformation and metamorphism between the Algonkian and the Pale-

[a] Lane, A. C., The early surroundings of life: Science, vol. 26, 1907, pp. 129–143.

ozoic are not sufficient to serve any useful purpose in correlation from province to province. Thus the Algonkian of the Lake Superior region is much less metamorphosed than the Paleozoic rocks of New England. At most these criteria can be used only for discriminations in the same region. Thus in the Lake Superior region the Algonkian rocks are, on the average, more metamorphosed than the Cambrian, but the upper Keweenawan sandstones differ little from the Cambrian in degree of metamorphism.

UNCONFORMITY BENEATH THE CAMBRIAN.

In late Algonkian time a large part of the Algonkian continent was above water and undergoing erosion. With the ensuing encroachment of the sea, perhaps from the southeast, south, and southwest, there were deposited, onto the older basement over which the sea was transgressing, lower Cambrian, middle Cambrian, upper Cambrian, and Ordovician sediments, each successive series overlapping the earlier ones. Thus the unconformity at the base of the Cambrian slants across the base of each of the Cambrian series into the Ordovician. Also there is much evidence to show that this transgression began in late Algonkian time. Near the margins of the old Algonkian land areas are found Algonkian sediments which appear to be in continuous downward conformable succession below the Cambrian rocks. Thus in the southern Appalachian area about half of the so-called Ocoee sediments extends downward conformably several thousand feet below the known *Olenellus* beds, and in the Wasatch and Uinta mountains a great quartzite series extends for 12,000 feet conformably below the *Olenellus* horizon. The Bow River group of British Columbia is thought by Walcott possibly to represent continuous deposition between the Belt Algonkian and the Cambrian. The question naturally arises whether these nonfossiliferous downward extensions of the *Olenellus* beds shall be called Cambrian or Algonkian, especially in view of the fact that they are separated from Algonkian rocks below by great unconformities. Since the base of the Cambrian has been defined as marked by the *Olenellus* horizon, the great conformable downward extensions have been thrown tentatively into the pre-Cambrian, and at the present time there seems to be no adequate reason for changing this usage, although in the future evidence sufficient for including some of these formations with the Paleozoic may appear. If the unconformity at the base rather than the *Olenellus* horizon be taken as the dividing plane, it would be necessary, at places of continuous sedimentation between Algonkian and Cambrian, to include considerable parts of the so-called Algonkian in the Cambrian, unless discriminative fossil evidence should be developed. Neither the paleontological nor the structural criteria are entirely satisfactory as a basis of classification where they conflict. The broad problem of harmonizing these criteria in a satisfactory classification remains open. In the meantime the paleontological basis for classification will be adhered to because for the most part it is in accord with structural evidence; it has been the accepted standard in the past.

The difficulty of determining the plane of demarcation between known Cambrian and pre-Cambrian series arises for only a small part of North America. For much the larger portion of the continent distinctly recognizable Cambrian rocks rest with profound unconformity upon distinctly recognizable pre-Cambrian rocks. Most of the Archean and Algonkian continent was practically base-leveled before and during the encroachment of the Cambrian sea. Occasional monadnocks stood out upon this plain. About these the base of the Cambrian is marked by coarse conglomerates, but for the most part the disintegrated and decomposed surface of the peneplain yielded, to the encroaching Cambrian sea, above conglomerate beds of only moderate thickness, somewhat fine-grained and well-assorted fragmental sediments, such as quartz sands and muds.

Difficulty in discriminating the Cambrian from the pre-Cambrian rocks sometimes arises from the fact that for extensive areas the lowest recognizable Cambrian rocks are of upper Cambrian age, unconformably below which are nonfossiliferous rocks referred to the Algonkian. Because the overlying rocks are upper Cambrian, in some cases it has been argued that the lower rocks are Cambrian. This position has been taken in reference to the Keweenawan series of the Lake Superior region, its nonfossiliferous character being explained by volcanism during its deposition. In cases of this sort no hard and fast rule can be laid down for their classification, but each case should be decided independently on its own merits. In the Lake Superior region it is believed that the magnitude of the unconformity separating the Cambrian from the Keweenawan, with the great thickness of the Keweenawan and the lack of fossiliferous content, combined with the fact that this unconformity is a part of the great slanting unconformity already mentioned as extending over a large part of the continent, the deposition of which extended from Algonkian to Ordovician time, throws the probability strongly toward the pre-Cambrian age of the Keweenawan rocks. (See pp. 349–351.)

UNCONFORMITIES WITHIN THE ALGONKIAN.

Three marked unconformities are known within the Algonkian of the Lake Superior and Lake Huron regions. These are evidenced by basal conglomerates, by erosion of the underlying series, by differences of amount of volcanism, by differences in metamorphism, and by the field distribution. The evidence is such that their importance can not be doubted.

While these unconformities doubtless do mark unequal intervals of time, no evidence is available to justify the emphasis of one of them more than another. However, Lawson has selected the unconformity below the Animikie as of greatest importance and has named it the "Eparchean interval." Where the Animikie rests directly upon the lower Huronian or the Archean this unconformity is naturally greater than where it rests upon the middle Huronian, for in such cases the unconformity at the base of the Animikie marks not merely one unconformity but is equivalent to two or three elsewhere with the intervening groups. It is plain that the relative importance of the various unconformities can be determined only where the succession is full and where therefore the Animikie is in contact with the underlying middle Huronian. Where this is the case, as in the Marquette district, there is no evidence whatever that the unconformity at the base of the Animikie is more important than the one separating the middle and the lower Huronian, or the one separating the Animikie and the Keweenawan, and in the Crystal Falls and Menominee districts this unconformity is very slight or lacking.

In no other part of North America have so many unconformities within the Algonkian been determined as in the Lake Superior region. Over the great northern area of Canada it is probable that all three of the unconformities are represented, but there have been detailed mapping and correlation in but limited areas.

In the Grand Canyon district is exposed an unconformity between the two groups of the Algonkian.

In Montana an unconformity is supposed to exist between the Belt series and the Cherry Creek group, believed to belong to the Algonkian, although such unconformity has not been proved.

In general, outside of the Lake Superior and Lake Huron regions unconformities within the Algonkian have been inferred at a number of places, but the only definitely proved unconformity is in the Grand Canyon region.

Each of the Algonkian unconformities may be represented elsewhere in North America by a continuous section of sediments. To what extent this is true is not yet known. The discussion of the correlation shows how fragmentary is the knowledge on which we must rely to decide this matter.

UNCONFORMITY BETWEEN ALGONKIAN AND ARCHEAN.

In large areas of the Lake Superior region the Archean was nearly base-leveled before the deposition of the Algonkian. The contrast of the two systems in volcanism, in metamorphism, and in relative amounts of sediments is striking. Anyone who has seen the evenly bedded Algonkian sediments resting upon the erosion edges of the gnarled and contorted complex of Archean schists, gneisses, and other rocks would not question the conclusion that this unconformity is a great one.

Similar statements may be made for the Lake Huron region and for the great northern interior of Canada, although here detailed mapping has covered but limited areas.

Locally in both of the regions deformation has nearly or quite obliterated the unconformity. In places also the basal member of the Algonkian is a little-assorted conglomerate made up of fragments like the immediately underlying rock. Some of the greenstone conglomerates of this horizon, composed of fragments of the underlying greenstone, are distinguished with great difficulty from the tuffaceous phases of the underlying greenstone.

For New Brunswick and Cape Breton the unconformity between the Algonkian Grenville and the Archean has not been determined, though it doubtless exists.

In Newfoundland there is a strong unconformity between the Algonkian Avalon and the Laurentian gneisses.

The only district in eastern United States where there has been an attempt to separate Algonkian and Archean rocks by an unconformity is in the southern Appalachians, where certain effusive rocks are classed as Algonkian, while the much deformed and metamorphosed plutonic rocks upon which they rest are called Archean. This is an unconformity between eruptive rocks, which may be of an order different from that of the unconformities above discussed.

In the Grand Canyon of the Colorado the unconformity is striking. Here evenly bedded Algonkian sediments may be seen resting upon a nearly even erosion surface truncating gneisses and schists of the greatest lithological variety and intricacy of structure.

In the Front Range of Colorado and in the Medicine Bow Mountains of Wyoming, and elsewhere in these States, an unconformity between the Algonkian and the Archean is known, but it is not conspicuous. The deformation which the rocks have undergone has developed a parallel schistosity in the Algonkian and Archean rocks which has largely obscured the true relations.

The quartzite of the Wasatch Mountains of Utah, provisionally assigned to the Algonkian, rests upon the Archean with tremendous unconformity. The Belt series of Montana also is unconformable upon the Archean with marked discordance.

In various other parts of the West unconformities between the Algonkian and the Archean have been inferred, but not actually observed.

In general wherever an unconformity between the Algonkian and the Archean is known there is likely to be evidence of long-continued erosion of the Archean rocks prior to the deposition of the Algonkian. The basal Algonkian sediments are so frequently of a cleanly sorted quartz-sand type as to imply a preceding period of weathering of long duration.

Theoretically there should be some place where sedimentation was continuous between the Archean and the Algonkian, for sedimentary rocks are known in both. Such places may be found, but positive proof of such continuity is not yet known. A number of geologists have cited cases of "gradation" between the rocks here designated Archean and Algonkian, but wherever the localities have been examined it has been found that progressive metamorphism has probably obliterated the evidence of unconformity.

CORRELATION OF PRE-CAMBRIAN SERIES.

In relative amount of deformation and metamorphism, in lithology, in relative abundance of igneous and sedimentary rocks, in stratigraphy, in the number of unconformities, and above all in our knowledge concerning these rocks, there is wide variation among the pre-Cambrian areas of North America. Notwithstanding these difficulties, we are able, for many regions, to apply the dual classification of the pre-Cambrian—Archean and Algonkian.

It has been intimated that the Archean and Algonkian are equivalent in magnitude to the Paleozoic and Mesozoic. The Paleozoic is divided into systems upon the basis of fossil evidence. In the Lake Superior region is a fauna called Silurian, similar to the fauna in the Silurian rocks of New York and Wales, but no way has been found to tell whether one of the Algonkian series of the Lake Superior region is equivalent to one which occurs in the Grand Canyon district, in Scotland, or in China. The science of geology has not sufficiently advanced to correlate the pre-Cambrian rocks upon a physical basis from province to province. When the physical history of the continents has been worked out, when we know more about paleogeography, and when we learn how extensive are the great unconformities, we may be able to correlate the pre-Cambrian series from province to province and possibly even from continent to continent. Because of these facts, no attempt is made to correlate the several series of the Algonkian in different geological provinces with one another. However, since the classification of the Archean rocks is upon the basis of lithology rather than upon stratigraphy, we do not hesitate to carry over to certain provinces the series terms Keewatin and Laurentian, using them with the same significance given to them in their type locality, the Lake Superior region.

In the following table the areas named are not each a separate geological province, but may be parts of the same province which have been reported upon in different States or by different observers. Within these provinces certain correlations of series are indicated. For instance, it will be noted that fairly detailed correlation of the Algonkian formations and series is possible at the present time through the Lake Superior and Lake Huron regions and adjacent parts of Canada. In other parts of Canada the lithological similarities are such as frequently to suggest correlation with series or formations, but such correlation can not be positive in advance of detailed work. In the West the great Belt series of Montana has been found to extend into Idaho and British Columbia. Probably to be correlated with it are the quartzites of the Uinta and Wasatch mountains, and perhaps also of the Needle Mountains in southwestern Colorado and of the Grand Canyon. The Belt series in its now known extent constitutes the greatest area of Algonkian on the continent, and it may be that this area should be extended to include Utah, Colorado, and Arizona quartzites. The part of the Ocoee group of the southern Appalachians conformably beneath the known Cambrian as here defined may also be provisionally correlated with the Belt series. The great series of volcanics of the southern Appalachians is correlated with volcanics of Maryland and Pennsylvania, and their stratigraphic relations seem to put them into the Algonkian. For the remainder of the country correlation of subdivisions of the Algonkian is not yet possible.

Table of correlation of pre-Cambrian rocks of North America.

Lake Superior region. (For detailed correlation see pp. 328-329.)	Lake Huron region. (For detailed correlation see p. 443.)	Rainy Lake, Lake of the Woods, and adjacent territory.
Algonkian: Keweenawan series. Sediments and intrusives and extrusives. Unconformity. Huronian series. Upper Huronian (Animikie). Unconformity. Middle Huronian. Unconformity. Lower Huronian. } Sediments, with intrusives and extrusives.	Algonkian: Huronian series. Upper Huronian (Animikie) of Sudbury district. Unconformity. Middle Huronian. Unconformity. Lower Huronian. } Sediments, with intrusives and extrusives.	Algonkian: Huronian series. Sediments, mainly slates and mica schists, with intrusives and extrusives, probably lower Huronian. Previously mapped in part as "Coutchiching" series.
Unconformity.	Unconformity.	Unconformity.
Archean: Laurentian series. Granites and gneisses, intrusive into Keewatin. Keewatin series (formerly "Mareniscan"). Greenstones, green schists, with some slate and iron formation.	Archean: Laurentian series. Granites and gneisses, intrusive into Keewatin. Keewatin series. Thessalon group (greenstones and green schists, mapped by Logan and Murray as "Huronian" slate).	Archean: Laurentian series. Granites and gneisses, intrusive into Keewatin. Keewatin series. Greenstones, green schists, with some slate and iron. Previously mapped in small part as "Coutchiching."

Northern interior of Canada.	Original Laurentian district.	Hastings district.
Algonkian: Keweenawan { Copper Mine River trap. Copper-bearing series of Hudson Bay. Huronian. Sediments, with intrusives and extrusives, as yet largely undifferentiated from greenstones and green schists of Archean age. Unconformity. Archean: Laurentian. Granites and gneisses, intrusive into Keewatin. Keewatin. Greenstones, green schists, and iron formation, largely mapped as Huronian.	Unclassified: Grenville series, consisting of limestones with associated conglomerates and gneisses of sedimentary origin; also granites, gneisses, and greenstones of igneous origin, at least partly intrusive into the Grenville series. Probably to be correlated with Grenville of Hastings district, Adirondacks, southeastern New York, and New Jersey. Position too doubtful to warrant correlation with Archean or Algonkian.	Unclassified: Two unconformable series, the upper of which (Hastings), according to Miller, carries limestone and is probably to be correlated with the Huronian. The lower series, also carrying limestone, is associated with gneisses of sedimentary origin and granites and gneisses of igneous origin, at least partly intrusive into the sediments. The lower sedimentary series rests on a basement of basic igneous flows similar to the Keewatin of the Lake Superior region. This series is to be correlated with the Grenville of the original Laurentian district. Miller therefore correlates this series with the Lake Superior Keewatin.

Table of correlation of pre-Cambrian rocks of North America—Continued.

Adirondacks.	Eastern Townships.	New Brunswick.
Unclassified: Grenville. Limestones with associated conglomerates and gneisses of sedimentary origin, with gneisses of unknown origin, and with granites, gneisses, and greenstones of igneous origin, partly intrusive into the sediments and largely with unknown relations. Correlated with Grenville series of original Laurentian and Hastings districts, and perhaps also with upper series of Hastings district. Succession is still too doubtful to warrant correlation of the series as a whole with Algonkian and Archean.	Unclassified pre-Cambrian (?): Volcanic rocks, associated with sediments of possible pre-Cambrian age, of Sutton, Stokes, and Lake Megantic areas.	Algonkian (?): Kingston group. "Huronian" slates, schists, and diorites. Unclassified: Grenville. Limestone, quartzites, and gneisses. Laurentian. Gneisses and schists, partly intrusive into the Grenville series. } Southern New Brunswick. Undivided sediments. Central New Brunswick.

Nova Scotia and Cape Breton.	Newfoundland.	Gaspe Peninsula.
Algonkian: Gold-bearing series in southeastern Nova Scotia. Correspond in stratigraphic position supposedly with Avalon, Ocoee, and other late Algonkian rocks of eastern America. Undivided sediments cut by intrusives. Unclassified: Granites and gneisses, largely intrusive into sedimentary series (mapped Laurentian).	Algonkian: Avalon group. Sediments intruded by granite and associated with volcanic conglomerates and ashes. Unclassified: Granites, gneisses, and schists of doubtful relations to Avalon group (mapped Laurentian).	Unclassified pre-Cambrian: Gneisses, schists, and sediments of Shickshock Mountains.

New England.	Southeastern New York.	Highlands of New Jersey.
Unclassified pre-Cambrian: Some of the discriminated units are— Mendon schist of Vermont (?). Mount Holly group of Vermont (?). Northbridge gneiss of Rhode Island. Stamford gneiss. Becket gneiss. Washington gneiss. Colesbrook limestone. Hinsdale gneiss. } Southwestern New England.	Algonkian (?): "Inwood" limestone and "Manhattan" schist (?), according to Berkey. Regarded as Paleozoic by Merrill and Eckel. ——Unconformity.—— Unclassified: Fordham gneiss, continuous with gneisses and sediments of the New York Highlands, with gneisses of New Jersey, and with the Becket gneiss of New England. Probably the equivalent of the Grenville series.	Unclassified pre-Cambrian: White limestones and gneisses, largely igneous and intrusive, partly of unknown age and relations. Probably equivalent, in part at least, of Grenville series.

Table of correlation of pre-Cambrian rocks of North America—Continued.

Pennsylvania.	Maryland and adjacent parts of Virginia.	Piedmont Plateau and adjacent portions of the southern Appalachians in Alabama, Georgia, Tennessee, North Carolina, South Carolina, and southern Virginia.
Algonkian (?): Volcanics of South Mountain. Continuous with volcanics of Piedmont. Wissahickon mica gneiss. Gneisses of Highland region.	Algonkian (?): Volcanic rocks. Continuous with volcanics of Piedmont. Wissahickon mica gneiss. Plutonic igneous rocks—age in part doubtful.	Cambro-Algonkian: Part of Ocoee representing conformable downward extension of the Cambrian beneath now known *Olenellus*. Possibly to be correlated with Belt and equivalent series of the West. Unconformity. Algonkian (?) (Keith): Metarhyolite. Andesite. Flattop schist. Catoctin schist. Montezuma schist. Linville metadiabase. Fragmental volcanics of North and South Carolina boundary.
Unconformity (?).	Unconformity (?).	Unconformity.
Archean (?): Baltimore gneiss (sedimentary) of Philadelphia area. (Corresponds to Carolina gneiss of Piedmont.)	Archean (?): Baltimore gneiss (sedimentary). (Corresponds to Carolina gneiss of Piedmont.)	Archean (?) (Keith): Granites, gneisses, schists. Largely unclassified. Discriminated units are (Keith)— Max Patch granite. Beech granite. Blowing Rock gneiss. Henderson granite. Cranberry granite. The soapstone group. Roan gneiss. Carolina gneiss (sedimentary in part).

Baraboo, Waterloo, Necedah, and Sioux areas of Wisconsin and Minnesota.	Missouri.	Oklahoma.
Algonkian: Quartzite. In the Baraboo district a quartzite is overlain conformably by slate and ferruginous dolomite. Intrusive granite. Unconformity. Archean: Acidic volcanics and granites of the Baraboo district and of Fox River valley (?).	Algonkian (?): Iron formation of Pilot Knob and Iron Mountain and associated granite and porphyry.	Unclassified pre-Cambrian: Granites, gneisses, porphyries, and gabbros of northeastern Oklahoma, in Wichita and Arbuckle mountains of south-central Oklahoma and in Ouachita Mountains of southwestern Oklahoma.

Table of correlation of pre-Cambrian rocks of North America—Continued.

Texas.	Black Hills.	Wyoming.	
Algonkian (?): Central Texas. Llano series. Sediments and schists, intruded by granites and gneisses. Western Texas (El Paso County). Sediments and schists in Franklin and Diablo mountains, intruded by granite.	Algonkian: Slates, quartzites, schists, and iron formation, intruded by granite.	Algonkian: Granites and gneisses intrusive in sediments listed below. Whalen group of Hartville district. Isolated areas between Hartville and Black Hills. Mica schists of Sundance quadrangle. Sediments in Hallock and Plumbago canyons, in the Sierra Madre (Grand Encampment), in Medicine Bow Mountains, in Seminoe Mountains, in Sweetwater district of the Wind River Range, and in Mount Sheridan near Yellowstone Park.	Unclassified pre-Cambrian: Granites and gneisses of Sierra Madre, Medicine Bow, Laramie, Sweetwater, Wind River, Wyoming, Rattlesnake, Gros Ventre, Teton, Absaroka, and Bighorn ranges.

Colorado.	New Mexico.	Arizona.
Algonkian: Sediments, mainly quartzite, of Needle Mountains, Uncompahgre Canyon, Rico Mountains, and Front Range. Perhaps also quartzite of Salida district. Quartzites of Needle Mountains perhaps to be specifically correlated with the Belt series of Montana and the quartzites of the Uinta and Wasatch mountains and the Grand Canyon. Certain greenstone schists and allied rocks of Salida district and Needle Mountains. Intruded by large masses of granite, such as Pikes Peak granite.	Unclassified pre-Cambrian: Granites, gneisses, schists, quartzites, and other sediments of central mountain system, including Mora, Taos, Santa Fe, Sandia, Magdalena, Caballos, and Franklin mountains; also Burro and other ranges of desert-range province.	Algonkian (late): Grand Canyon group. Perhaps to be specifically correlated with the Belt series of Montana and the quartzites of Needle, Wasatch, and Uinta mountains. } Chuar group. Unkar group. Pinal schist (sedimentary) of southeastern Arizona, including Globe, Bisbee, and Bradshaw districts (?), possibly to be correlated with Grand Canyon series.
——Unconformity.——		——Unconformity.——
Archean (?): Granites, gneisses, and schists of Front, Wet, Sangre de Cristo, Sawatch, and Needle mountains. May include sedimentary schists of Front Range.		Archean: Granites, gneisses, and schists of Grand Canyon.

Table of correlation of pre-Cambrian rocks of North America—Continued.

Nevada.	Utah.	Idaho.	Montana.
Algonkian (late ?): Quartzites of Schell Creek, Egan, Pogonip, Snake River, and Piñon ranges.	Algonkian (late): Quartzites of the Uinta and Wasatch mountains. To be correlated specifically with the Belt series and possibly also with the quartzites of Needle Mountains and the Grand Canyon. Quartzites and schists of Promontory Ridge and of Fremont Island and Antelope Island mountains (?).	Algonkian (late): Belt series of northern part of State. Unclassified pre-Cambrian, older than Belt series; partly Archean (?): Granites, gneisses, and sediments of Clearwater and Bitterroot mountains. Schists, gneisses, and granites west of Belt area in northwest corner of State.	Algonkian (late): Belt series with extensions into Idaho and British Columbia. To be correlated with the quartzites of the Uinta and Wasatch mountains and perhaps also quartzites of Needle Mountains and the Grand Canyon. Algonkian (early): Cherry Creek group. Intrusive granites and gneisses.
——Unconformity.——	——Unconformity.——		——Unconformity (?).——
Archean (?): Granites and gneisses of Snake River and other ranges.	Archean (?): Granites, gneisses, and schists (in part) of Wasatch Mountains, Promontory Ridge, Fremont Island, and Antelope Island (?). Schists and quartzites of Red Creek Canyon in Uinta Mountains (?).		Archean (?): Granites and gneisses of mountain ranges of southwestern part of State.

Washington, Oregon, and California.	British Columbia, Yukon, and Alaska.		Mexico.
Unclassified pre-Cambrian (?): Gneisses, schists, sediments, and volcanics of northern Cascades and International Boundary region of northeastern Washington, Klamath Mountains of Oregon and California, and other districts.	Algonkian (late): Belt (?): Nisconlith group and part of Adams Lake group of British Columbia. Belt series of boundary region. Downward extension of Bow River group.	Doubtfully pre-Cambrian: Birch Creek schist of Tanana-Yukon region. Totsen group of northern Alaska. Indian River group of Klondike. Kuzitrin group of Seward Peninsula. Kigluaik group of Seward Peninsula. Unclassified pre-Cambrian: Shuswap group and "Laurentian" series of British Columbia. Contains rocks probably belonging to both the Archean and the Algonkian. Pelly gneiss (?).	Unclassified pre-Cambrian: Crystalline schists and granites, principally along the Pacific slope.

The correspondence of Algonkian rocks in various parts of America with reference to lithology and succession is, thus, far from close, but it may be pointed out that close correspondence is scarcely to be expected, even if the rocks are of the same age. To quote Chamberlin and Salisbury:[a]

The phases of sedimentation taking place about any land mass at any time are largely dependent upon the height of the land, the freeness of the exposure of its coasts, the amount of precipitation, the climate, and the character of the formations suffering erosion. These various factors were as likely to be dissimilar about the various centers of sedimentation as to correspond. Igneous rocks form a not inconsiderable part of the Proterozoic systems, and there is no law requiring igneous activities in different regions to correspond either in time or in the nature of their products. Even body deformations, which are much the most general, and which are the basis for the subdivision of the systems, need not have corresponded in their particular phases in different regions. It follows (1) that the number of series with the Proterozoic in one place may not be the same as in another; (2) that the thickness of the various systems may vary within wide limits; (3) that there need have been no close correspondence in the sorts of rock in different regions at the outset, and (4) that they may have been metamorphosed unequally since their deposition.

Even where there is some correspondence between two pre-Cambrian successions, this may not be apparent because of difference in amount of study which has been given to the two regions, or because the characters of one or both successions have been obscured by structural and metamorphic changes or in part removed by erosion.

PRE-CAMBRIAN ROCKS OF OTHER COUNTRIES.

Little has been done toward the correlation of the pre-Cambrian rocks of North America with those of other countries. Similarities in the broader features, however, are beginning to be apparent. The pre-Cambrian of Europe, as in the United States, may be divided into a basal complex characterized by gneiss, schist, and granite, unconformably overlain by a series dominantly sedimentary, for the most part lacking fossils but showing a few slight traces of them. The former corresponds to the Archean, the latter to the Algonkian. It is significant that the terms Archean and Algonkian are beginning to appear in this sense on some of the European maps.

BRITISH ISLES.

The Northwest Highlands of Scotland afford one of the most continuously exposed sections of pre-Cambrian rocks known. The members of the Geological Survey of Great Britain have mapped the area with great care, using as a base the British 6-inch Ordnance maps.

[a] Text-book of geology, vol. 2, 1906, pp. 214–215.

The results of their long labors appear in an excellent memoir published in 1907.[a]

Their succession is as follows:[b]

IV. Eastern schists	Flaggy quartz schists, quartz-biotite granulites and garnetiferous muscovite-biotite schists, with occasional inliers of deformed or reconstructed Lewisian gneiss. Zone of mylonized rocks usually at the base of this series.
Great disruption line—the Moine thrust—which has driven the Eastern schists (IV) over the rocks below (III, II, I).	
III. Cambrian	3. Dolomites and limestones, with certain fossiliferous zones. 2. Serpulite grit and fucoid beds yielding the *Olenellus* fauna. 1. Quartzites with worm casts in the upper portions and false-bedded grits below.
Unconformability—plane of marine denudation.	
II. Torridonian	3. Sandstones and dark micaceous shales. 2. Thick series of coarse sandstones and grits with conglomerate bands. 1. Dark and gray shales with calcareous bands, fine-grained sandstones, and grits with epidotic grits at the base.
Strong unconformability—highly eroded land surface.	
I. Lewisian	2. A great series of igneous rocks intrusive in that complex, in the form of dikes and sills. 1. A fundamental complex, composed— (*a*) Mainly of gneisses that have affinities, both chemically and mineralogically, with plutonic igneous products, and (*b*) Partly of crystalline schists, which may be regarded as probably of sedimentary origin.

As to the importance of the unconformity between the Torridonian and the Lewisian, Horne says:[c]

One of the most impressive features in the history of the Lewisian gneiss is the abundant evidence of prolonged denudation between the cessation of the terrestrial movements just described and the deposition of the Torridon sandstone. During the protracted interval represented by this denudation the gneiss plateau formed a land surface which was carved into lofty hills with craggy slopes and deep valleys. This fragment of primeval Europe has been preserved under the pile of coarse Torridonian grits and sandstones which is now undergoing slow removal by the agents of waste. The observer may climb one of these Archean hills, following the boundary line between the Lewisian rocks and the younger formation, and note, step by step, how the subangular fragments of hornblende schist that fell from the pre-Torridonian crags are intercalated in the grits and sandstones, thus indicating the slow submergence of the old land

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[a] The geological structure of the Northwest Highlands of Scotland, by B. N. Peach, John Horne, the late W. Gunn, C. T. Clough, and L. W. Hinxman, with petrological chapters and notes by J. J. H. Teall. Edited by Sir Archibald Geikie. Mem. Geol. Survey of Great Britain, 1907.

[b] Op. cit., pp. 9–10, 33.

[c] Op. cit., p. 4.

surface beneath the waters of Torridonian time. Between Lake Maree and Loch Broom it is possible to determine the orientation of these buried valleys and to prove that some of the hills exceeded 2,000 feet in height.

In the memoir the Lewisian system is often referred to as the "Fundamental complex" in exactly the same sense as we have used the term in the Lake Superior region for the pre-Algonkian system. Indeed, the Scotland "Fundamental complex" has all the characteristics of that of the Lake Superior region. After years of work by several men much the larger part of the Lewisian is mapped as "undifferentiated"—that is, it has not been possible in western Scotland, with the splendid exposures of the region and with 6 inches to the mile Ordnance maps of the highest quality, to separate the fundamental complex into formations, except for small areas. Probably nowhere else in the world are the opportunities better to make such separation, if this were possible, and certainly no other geological survey has ever spent more than a small fraction of the time given by the Scotland Survey to a small area of the fundamental complex.

The petrographic descriptions show that the Lewisian is dominantly composed of igneous rocks, of which the granitic type is most abundant, and that the sediments are extremely subordinate. The latter rocks include "mica schists, graphitic schists, quartz schists, siliceous granulites, limestones, dolomites, and cipolins." [a]

The relations of the sediments of the Lewisian to the igneous series have not been entirely worked out. Horne says: [b]

> There is no clear evidence that these types are intrusive in the former, but in certain places the two are so intimately associated as to suggest that the rocks of igneous origin may have been injected into those of sedimentary origin. On the other hand, there is undoubted proof that, north of Lake Maree, the altered sediments rest on a platform of gneiss and are locally overlain by gneiss with basic dikes, the superposition of the gneiss on the sediments being there due to folding and thrusting.

In the strongest possible contrast with the Lewisian is the Torridonian. Here ordinary stratigraphic methods apply, and the system has been divided into three formations.

It is clear that under the general classification advocated in this report the Torridonian is Algonkian and the Lewisian is Archean. While the foldings, faultings, intrusions, and metamorphisms of the Archean have been so extreme and the relations of the different rocks so intricate that upon the general geological maps there has been no attempt to subdivide the fundamental complex, the descriptions show that in the central district basic rocks are developed in great force with subordinate amounts of ultra-basic rocks, and that in the

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[a] Op. cit., p. 75.

[b] Op. cit., p. 4.

northern and southern districts the acidic rocks are dominant. Moreover, it is stated that the basic rocks are oldest and are intruded by the acidic gneisses. Thus we apparently have in the Archean complex the equivalent of the Keewatin and Laurentian, as we use these terms in America, with like relations.

The Scotland area also is one which illustrates the faulting deformation of the pre-Cambrian upon a great scale, which also affects the post-Cambrian rocks. As a result of most remarkable overthrust faults developed in the post-Cambrian, the eastern rocks were driven toward the west, were folded over one another, snapped across, and piled up in successive slices, giving gently dipping eastward limbs and steeply inclined western limbs. The more westerly of these thrusts detach, bring up, and drive westward portions of the old floor of Lewisian gneiss, together with the Torridon sandstone and many of the fossiliferous zones of the Cambrian. The slices of Lewisian gneiss sometimes exceed 1,000 feet in thickness, and they present the characteristic types of these rocks as developed in the undisturbed area to the west. In certain localities inversions occur on a stupendous scale, as, for example, to the north and south of Strome Ferry, where a portion of the old Archean floor of gneiss has been turned upside down and reposes on the inverted basal beds of the Torridon sandstone, which dip at gentle angles to the east-southeast.

The most easterly and perhaps the most powerful of these disruptions, to which the name "Moine thrust" has been given, differs from all those to the west in two important points. First, the materials overlying that plane comprise the Eastern schists, which possess different petrographical characters from the displaced masses to the west. Secondly, in some instances the strata overlying this plane have been driven so far west—for 10 miles at least in the Durness area—that they rest almost directly on the undisturbed Cambrian rocks. Hence arise those deceptive sections where there seems to be a normal sequence from the fossiliferous Cambrian zones into the Eastern schists.

In England and Wales the pre-Cambrian occupies small areas and its stratigraphy is less well known.

SCANDINAVIA.

Scandinavia exhibits the largest continuous tract of pre-Cambrian rocks in Europe. They may be regarded as an extension on the mainland of those of Britain and are believed by Geikie to be similar in general geological features. In western Norway the Archean may be represented by coarse banded gneiss, sometimes with limestone bands, occupying large areas. This corresponds to the Lewisian gneiss of England. With it is intimately associated another group of rocks, consisting of quartzite, limestone, mica schist, and quartz schist, predominantly of sedimentary origin. This is certainly older than some of the gneisses, which can be seen to pierce it. It is similar to the Dalradian series of Scotland. Resting upon the gneisses unconformably is a later group of mica schists, phyllites, quartz schists, clay slates, quartzites, and schistose conglomerates, associated with schists probably of eruptive origin. The age of this group is not clear; part of it is as late as Silurian, part of it may well be Algonkian. The similarity of a part of these rocks to the Torridonian series is close.

In Sweden a similar subdivision of the pre-Cambrian rocks is possible. The terms Algonkian and Proterozoic have been applied by Törnebohm to cover the pre-Cambrian sedimentary rocks. He divides these rocks into Upper and Lower Algonkian. His upper series is doubtless Algonkian as we use the term, but it is not certain that the lower series is not Archean, at least in part. There is marked difference between the pre-Cambrian on the eastern and western sides of the Scandinavian peninsula, and the western side also has been subjected to much more metamorphism than the eastern side. The content of iron ores is a feature which emphasizes their similarity to the Lake Superior pre-Cambrian.

FINLAND.

Most of Finland is covered by pre-Cambrian rocks with characters similar to those of Sweden.

Sederholm,[a] in 1907, discusses the pre-Cambrian geology of eastern "Fenno-Scandia," especially the origin of the granites and gneisses, and presents a geological map of "Fenno-Scandia." The succession is as follows:

Succession of pre-Cambrian rocks in "Fenno-Scandia."

Names of the subdivisions.	Supercrustal rocks.	Infracrustal rocks.
Jotnian.	Diabases, sandstones, labradorites, conglomerates.	Rapakivi granites.
Unconformity.		

[a] Sederholm, J. J., Om Granit och Gneiss, deras uppkomst, uppträdande och utbredning inom urberget i Fennoskandia: Bull. Comm. Géol. de Finlande, No. 23, 1907. (With English summary of contents.

Succession of pre-Cambrian rocks in "Fenno-Scandia"—Continued.

Names of the subdivisions.		Supercrustal rocks.	Infracrustal rocks.
Jatulian.	Upper Jatulian. (Onegian).	Augite porphyries and their tuffs, "metabasites," anthracite, dolomites, slates, sandstones.	
	Lower Jatulian.	"Metabasites," dolomites, quartzites and quartzitic sandstones, conglomerates.	
Unconformity.			
Kalevian.	Upper Kalevian.	"Metabasites," quartzites, conglomerates.	Post-Kalevian granites, injecting the Kalevian and older rocks, thus forming "veined gneisses."
	Unconformity.		
	Lower Kalevian.	"Metabasites," talc and chlorite schists, dolomites, phyllites, quartzites and quartzitic schists (often glassy), conglomerates.	
Unconformity.			Post-Bottnian granites, injecting the Bottnian and older rocks, thus forming "veined gneisses."
Bottnian.		Uralite porphyries and their tuffs, plagioclase porphyrites, conglomerates, phyllites, leptites, etc.	
Unconformity.			Post-Ladogian granites, diorites, amphibolites, etc., injecting the Ladogian and older rocks, thus forming "veined gneisses."
Ladogian.		Phyllites and mica schists, glassy quartzites, conglomerates (?), "metabasites," dolomitic limestones, hälleflintas, etc.	
Katarchean.		Granitic gneisses, "metabasites," etc.	

From this succession it appears that in Finland there are at least four pre-Cambrian sedimentary series. For the Jotnian, Jatulian, Kalevian, and Bottnian, Sederholm makes exactly the same point as has been made with reference to the Algonkian. He says:

At least as far back as during Bottnian time the climatic conditions were not sensibly different from those of later geological periods, as shown by the existence of rocks which, in spite of their metamorphic character, show themselves to be sediments with the same regular alternation of clayey and sandy material ("annual stratification") as the glacial clays of that same region, explainable only by assuming a regular *change of seasons.*[a]

[a] Op. cit., p. 95.

He further says the problem of the pre-Cambrian stratigraphy has been solved " in a decidedly actualistic direction." While Sederholm is too cautious to make any definite correlations with the Lake Superior region, he suggests that the Jotnian is similar to the Keweenawan of North America, the Jatulian equivalent to the Animikie or upper Huronian, and the Kalevian perhaps similar to the lower Huronian of North America. This suggested likeness is even greater when it is remembered that what was originally called the lower Huronian is now divided into the middle and lower Huronian, and that the Kalevian is divisible into two unconformable series.

These sedimentary series together are Algonkian. Unconformably below these are two series of rocks, the upper called the Ladogian, and this series is intruded by the granites and gneisses of the Katarchean. If we correlate these with the Archean as we use the terms, we may have in Finland two divisions of the Archean which correspond to the Keewatin and Laurentian. The essential difference is that in the Ladogian, equivalent in position to the Keewatin, the sedimentary rocks seem to be more important relatively than in America.

It is regarded as certain that some of the granites or gneisses have served as the basement upon which the sediments were deposited, that they have been remelted and have invaded the lower portions of the sediments; in other words, there has been subcrustal fusion, but such rocks are regarded and mapped as distinctly igneous and later than the sediments. The gneissose structure is regarded as partly original—that is, developed before the solidification of the rock—and partly developed secondarily under dynamic pressure. The author presents evidence of what he regards as partly fused, intermediate phases between the granite and the sediments. No evidence was found that petrographic character can serve as a basis for stratigraphic classification.

These conclusions are believed to cover a considerable part of " Fenno-Scandia."

RUSSIA AND CENTRAL EUROPE.

The pre-Cambrian of Russia and central Europe has for the most part not been satisfactorily subdivided and correlated, but it is known to include both igneous and sedimentary rocks and their metamorphosed equivalents. Algonkian and Archean are the major divisions for the pre-Cambrian found upon the official geological map of France published in 1905 under Michel Lévy as inspector-general, and compiled by a committee consisting of thirty-five geologists of that country with the assistance of a committee of fifty other geologists. In Bavaria and Bohemia the Archean may be represented by the lower series of gneiss and granite of that region, while the Algonkian may be represented by an upper series consisting of gneisses, schists, and limestones, grading up into clay slates and schist. The Algonkian is probably represented also by the metamorphosed sediments assigned to the pre-Cambrian in Germany and Spain. Presumably some of the gneisses, schists, and granites might be correlated with the Archean, but we are unable to state to what extent the present information warrants such correlation.

SOUTH AFRICA.

In South Africa the pre-Cambrian has not been subdivided. It is represented, according to Hatch and Corstorphine, by the Malmesbury series of micaceous slates and quartzites in southern Cape Colony, and by the Swaziland series of slate, quartzite, conglomerates, and schists of northern South Africa. All of these are associated with granites and gneisses, in part intrusive.

INDIA.

In India there are two series underlying the oldest Paleozoic formations. The oldest or Bunklekund gneiss is unconformably covered by metamorphic series. In the western Himalayas also there are two series, a lower gneiss and an upper gneiss, said to be formed by the metamorphism of the older Paleozoics, into which they pass.

AUSTRALASIA.

In New Zealand crystalline schists occupy large areas, but it is not known what part are pre-Cambrian. In Australia pre-Cambrian rocks are believed to cover an area of perhaps 20,000 square miles, but have not been subdivided. In Tasmania rocks of probable pre-Cambrian age occupy a large area on the west side of the island. They include both igneous and sedimentary rocks and their metamorphosed equivalents.

CHINA.

Through the researches of Baron von Richthofen the existence of pre-Cambrian rocks in China has long been known, and he pointed out that the Archean and certain later pre-Cambrian sedimentary series were extensively represented. The work of Willis and Blackwelder has confirmed Von Richthofen's observations and gives more definite information regarding the character and sequence of the rocks.

Throughout northern China there are extensive areas of basement complex, which is tentatively assigned to the Archean on the ground of its complex internal structure, probably predominant igneous character, and position at the base of the pre-Cambrian terranes. It includes limited amounts of marble and schists which are of sedimentary origin, but is dominantly composed of gneisses, believed to have been derived largely from igneous rocks, and is intruded by various igneous rocks, among which granite predominates. The principal occurrences of this complex which have been studied are in Shan-tung, northwestern Chi-li, and northern Shan-si.

The later pre-Cambrian formations of China have been discriminated best in the Wu-t'ai-shan Range in northern Shan-si. This range presents at least three and possibly four pre-Cambrian groups later than the Archean, divided by unconformities. Of the three which may be definitely recognized the older two constitute a sequence of quartzite, biotite schist, muscovite schist, and chlorite schist, with more or less marble. The structures are complex, embracing schistosity, isoclinal folding, and overthrust. Two groups are recognized as clearly distinct—the Nan-t'ai group of conglomerate, quartzite, and limestone, and the Si-t'ai group, consisting prevailingly of chlorite schist. The latter is believed to be the younger. A third group, designated the Shï-tsui group, consists largely of biotite and muscovite schists and quartzite. It is probably older than either of the others, but may represent some part of the Nan-t'ai. The collective name retained for the Nan-t'ai, Si-t'ai, and Shï-tsui groups is Wu-t'ai series, originally given by Von Richthofen.

Unconformably overlying the extensively altered Wu-t'ai series is a series of slates and limestones, which are but slightly metamorphosed and only moderately folded. The unconformity is recognized chiefly by the difference of metamorphism and of structure, as immediate contacts have not been oberved. The younger sequence has received the name Hu-t'o series. The exact succession has not been ascertained, but the base of the series appears to include conglomerate, quartzite, and gray slates; and that part of the series which is believed to constitute the upper half consists chiefly of flinty gray limestones with interbedded slates. The total thickness amounts to 2,000 feet or more.

Throughout the northern part of the province of Chi-li there occurs a pre-Cambrian limestone, which has received the name Ta-yang or Nan-k'ou limestone. At the observed contacts it rests unconformably upon the Archean with but a thin layer of argillite between them, and it is unconformably overlain by strata of lower or middle Cambrian age. This limestone may be the representative of the Hu-t'o series, but as the occurrences are widely separated and the stratigraphic relations are not precisely the same, correlation is not established.

The strata of the Hu-t'o series and the Nan-k'ou limestone closely resemble, in siliceous and calcareous character and in the very moderate degree of alteration which they have suffered, the Belt series of Montana. No fossils have been found in them, but it is not impossible that further search may be successful.

From the researches of Richthofen, Lóczy, Obrutchoff, and others it is known that pre-Cambrian rocks occur in many other mountain ranges in China. In some cases only the basal complex appears to be represented, while in others metamorphosed sedimentary strata have been observed.

According to Willis [a]—

A provisional classification of the Wu-t'ai and limiting systems in the type locality is as follows:

Hu-t'o series (neo-Proterozoic)	Tung-yü limestone; Tóu-ts'un slate	Slates, limestone, and quartzite.
Unconformity.		
Wu-t'ai series (eo-Proterozoic)	Si-t'ai group	Chiefly chlorite schist; quartzite conglomerate at the base.
	Unconformity.	
	Nan-t'ai group	Siliceous marble, quartzite, and schist.
	Unconformity.	
	Shï-tsui group	Mica schist, gneiss, magnetite quartzite, and basal feldspathic quartzite.
Unconformity.		
T'ai-shan complex (Archean)		Basal complex of varied gneisses and younger intrusives.

It has been seen that the Archean, or basement complex, consists dominantly of gneisses, probably in large part derived from igneous rocks. Within these gneisses are various intrusions, among which granite predominates. Very subordinate masses of sedimentary materials are found. In short, the descriptions of this complex show that it has all of the characteristics of the Archean. The four sedimentary groups unconformably above the Archean are composed of rocks which were originally muds, grits, conglomerates, and limestones. In other words, they have all of the characteristics of the Algonkian.

There is thus a remarkable similarity between the Archean and the Algonkian of China and similar systems in North America. Indeed,

[a] Willis, Bailey, and Blackwelder, Eliot, Research in China, vol. 1, Descriptive geology, pp. 109–123; vol. 2, Systematic geology, p. 4, Carnegie Inst., 1907.

the number of certainly recognized divisions of sedimentary rocks of pre-Cambrian age are precisely the same as in the Lake Superior region. Willis suggests that the three lower groups, which he places in the Wu-t'ai series, are equivalent to the Huronian of the Lake Superior region, which also is divisible into three unconformable parts. This would leave the Hu-t'o series to be correlated with the Keweenawan. It would not be well to emphasize too strongly this close correlation suggested, but certainly the similarity of the succession is astonishing and suggests the possibility that in the future we may be able to correlate the unconformable series in the Algonkian in provinces separated as far from one another as the Lake Superior region and northern China. The similarity of the succession in Finland gives additional emphasis to this suggestion.

In the classification of the Algonkian presented by Willis for China he introduces into the nomenclature of the pre-Cambrian the words neo-Proterozoic and eo-Proterozoic. We question this practice, since we can see no philosophical basis upon which such a division can be made, nor do the facts as they occur in the field seem to us to require any such division.

JAPAN.

The Imperial Geological Survey of Japan outlines the geology of Japan.[a] At the base of the column is the Archean group (in the sense of pre-Paleozoic), sedimentary phases of which occupy 3.4 per cent of the total area of Japan. The group comprises two systems. The lowest, the gneiss system, consists of gneiss, schists, and amphibolites, with intercalated limestone and granulites. It is described as similar in lithological character to the Laurentian of North America and to the oldest rocks found in Korea, China, and Siberia. The succeeding system, called the crystalline schists, consists of various schists of a phyllitic aspect, accompanied by serpentine and gabbro eruptives but not by granitic eruptives. The junction between the crystalline schist system and the gneiss system is generally indicated by faults. The crystalline schist system, according to the Japanese geologists, may correspond to the Algonkian of North America or to the phyllite system of Europe, but nothing can be said as regards the correlation, as the oldest fossiliferous series of the Paleozoic group has not yet been found in Japan.

GENERAL.

This brief and imperfect summary of the pre-Cambrian of other countries than North America brings out the significant fact that

[a] Outlines of the geology of Japan, descriptive text, with geological map of Japan, compiled by officials of the Imperial Geological Survey of Japan, Tokyo, 1902.

the oldest system is prevailingly gneissic and schistose, that it is dominantly of igneous origin, that it contains also sedimentary rocks, that between this system and the Paleozoic is a system of more or less metamorphosed sediments and volcanics which have locally been divided into series and formations, and that this system essentially lacks fossil remains, but shows traces of them. Between the two systems in various countries there are unconformities. The first system may be called Archean, the second Algonkian. Perhaps the most significant feature of all is the evidence of subordinate amounts of sediments in the Archean gneissic rocks, just as is now being found in North America.

HISTORY OF NAMES APPLIED TO PRE-CAMBRIAN ROCKS.

In the early days of American geology the name "Primary" or "Primitive" was more widely applied to the ancient rocks than any other. Among the older geologists this name, applied in a general way to the pre-fossiliferous or metamorphic rocks, was used by Akerly, Alexander, Booth, Dewey, Ducatel, Eaton, Emmons, Hitchcock (Edward), Jackson, Mather, Mitchell, Percival, Rogers (H. D.), Rogers (W. B.), Silliman, Tuomey, Vanuxem, and others. Its use was nearly universal in 1820 and it was applied as late as in the forties.

The term "Primitive" in the United States was gradually superseded by "Azoic." Used by Adams as early as in 1846, in the literature of the fifties and sixties it very widely occurs. Among more prominent geologists in whose writings it may be found are Adams, Cook, Crosby, Emmons (E.), Frazer, Hitchcock (C. H.), Hitchcock (E.), Kerr, Rogers (H. D.), Safford, Whitney, Wadsworth, and others. In its earlier use "Azoic" was often made to cover all rocks which were apparently destitute of life, without reference to whether they are older than the fossiliferous rocks or not. It was thus applied by Adams, Emmons (E.), and the elder Hitchcock. With Rogers the "Azoic" included nonfossiliferous rocks which are younger than the "Hypozoic" or gneissic series proper. Ordinarily, however, the term was used to cover all pre-Silurian sedimentary rocks, the Silurian being then regarded as the base of the fossiliferous systems. It was thus clearly defined by Foster and Whitney in their application of it to the Lake Superior rocks, and the "Azoic" was held by them to be structurally indivisible. While the rocks of the "Primitive" and "Azoic" were early subdivided into lithological divisions, there was little or no attempt to apply stratigraphic methods to them. Later the "Azoic" was subdivided by certain geologists into "Laurentian," "Huronian," etc.

The work of Logan and Murray marks in America the beginning of a truly structural study of the ancient rocks. In different places in Canada they found pre-Cambrian rocks, which they mapped in detail. The two areas in which this work was begun were the north shore of Lake Huron and the Laurentide Mountains. With scientific spirit they applied to the rocks of these areas no terms which involved any theory of origin or equivalence, but gave the rocks the names of the localities, in this following one of the fundamental principles of good structural work. Having no fossils for guides, they built up a succession on the north shore of Lake Huron by following formations in continuous exposure, by lithological likenesses of exposures separated by short intervals, by a like order of formations in different localities, and by the use of an unconformity, which was held to occur between the Huronian sediments and the underlying crystalline rocks.

In Logan's work on the "Laurentian" the same methods were used as far as practicable, but on account of the complicated structure of the region his success was here much less conspicuous. The difficulty of the district drove Logan to take the one characteristic formation, the limestones, as horizons to follow and to serve as planes of reference in working out the structure. But even this guide was not a certain one, as Logan never became quite sure as to the number of limestones present. As the study of the Laurentides continued the rocks were divided into two divisions, a "Lower Laurentian" free from limestone and an "Upper Laurentian" containing the limestones. The two were held by Vennor, and by Selwyn for a time, to be unconformable. As the area studied in the Laurentide Mountains widened, a new formation was found, a laminated gabbro. It was recognized as being largely composed of labradorite or anorthite and so was first called "Anorthosite" or "Labradorian," and afterward "Norian." The contacts of this formation with the other formations of the "Laurentian" were recognized as not those of conformity. In these early days it was naturally supposed that all laminated rocks, whatever their character, were sedimentary, and as in certain places the "Labradorian" appeared to cut across or overlap the old "Laurentian" it was designated "Upper Laurentian," and what had before been called "Upper Laurentian" was designated "Middle Laurentian." When the eruptive character of the "Labradorian" was shown, the Canadian Survey returned to the first uses of the terms "Upper Laurentian" and "Lower Laurentian."

In comparing the "Huronian" and "Laurentian" it appears that the principle used in reaching the conclusion that the original "Upper Laurentian," separated by a great distance from the original Huronian and nowhere in contact with it, is the older, was the metamorphic character of the former as compared with the latter, which in the early work of Logan and Murray was called a nonmetamorphic series. The lithological likeness of the gneisses and granites of the original "Lower Laurentian" to the granites and gneisses called

"Lower Laurentian" unconformably underlying the Huronian doubtless was the reason for placing these as equivalents.

In the later work of Logan and Murray the names "Huronian" and "Laurentian" were applied to regions far distant from the original areas, the guiding principles for so doing being wholly lithological likeness and degree of metamorphism. Working under these principles, as granites and granite gneisses are so abundant in the original Laurentian, and are nearly absent in the original Huronian, it became customary with these authors to refer to granitoid areas as "Laurentian," while sedimentary series containing quartzites, limestones, or dark, fine-grained schists were referred to the "Huronian," and this reference was frequently made when the series as a whole was very much more crystalline than the original Huronian. The only exception to a reference of all pre-Cambrian rocks to the Huronian and Laurentian were the rocks now known as Keweenawan series and Animikie group. These were recognized as resting unconformably upon the so-called "Huronian" of Lake Superior, while the Keweenawan was seen to be of a wholly different lithological character from the Lake Huron rocks. These series were called the "Upper Copper-bearing series," the original Huronian often being called the "Lower Copper-bearing series."

We find these two geologists, Logan and Murray, starting with scientific principles, laboriously studying year after year the detailed occurrences of the rocks in the midst of a forest-covered wilderness, until their inductions built up the "Original Huronian" and "Original Laurentian" series. In their later work, of a very much less detailed character, over vast areas the terms were applied somewhat indiscriminately and in such a way as to imply that below the "Upper Copper-bearing" rocks there are only two series, one of which is equivalent to the original Huronian and the other of which is equivalent to the original Laurentian.

These terms, Huronian and Laurentian, were gradually adopted by geologists working on the United States side of the boundary, so that in recent years, with the exception of Archean, they have been the most widely used names for designating the ancient rocks.

If Logan and Murray in their later work departed from strict scientific methods in the use of these terms, this departure was as nothing compared with the extremes to which later geologists of America have gone. By many geologists, coarse-grained granites and granite gneisses were designated "Laurentian" without reference to evidence as to whether they were intrusive rocks of far later age. In applying the term "Huronian" the methods followed were even worse. Sometimes authors took a green color to be a characteristic feature of the Huronian and here referred all the green schists; others took a laminated structure to be characteristic of the series and here referred all the laminated rock, including even coarse-grained laminated gneisses; others took the volcanics associated with the Huronian to be its characteristic feature and so called various pre-Cambrian volcanic rocks "Huronian;" others regarded metalliferous rocks as the important feature of the Huronian.

The real basis of all this work is the assumption that rocks of a certain kind are characteristic of a definite period of the world's history, and that if rocks are found which are really like the Huronian and Laurentian in lithological character they should be referred respectively to these series.

The Lake Superior region furnishes a rather marked exception, as do certain others, to the indiscriminate and unwarranted use of the term Huronian. This region is so near to and is connected in such a way with the original Huronian of Lake Huron that it was possible to make a strong case of probability in favor of the equivalence of the clastic rocks of the two regions. The Lake Superior Huronian was divided into formations upon the same principles that were used in mapping the original Huronian. While the term "Laurentian" was applied to the pre-Huronian rocks on the north shore of Lake Huron and about Lake Superior, a number of geologists recognized the fact that this was a variation from its application in the original Laurentian area.

As geological knowledge increased and as the theories involved in the terms "Primitive" and "Azoic" were more and more attacked, in order to avoid a theory of origin the term Archean was proposed for the ancient rocks by Dana in 1872. This term rapidly grew in favor. By its use not only the disadvantage of a theory of origin was avoided, but in common with "Primitive" and "Azoic" it was necessary to subdivide the ancient rocks into "Laurentian" and "Huronian," and thus imply a correlation with the rocks of other regions. In the early rapid work of the Far West, detailed observations usually stopped at the base of the fossiliferous series, and it was convenient to regard all the remaining rocks as a unit, and to cover this unit the term Archean was adopted. After a more detailed study of certain regions the terms "Laurentian" and "Huronian" were applied to subdivisions of the Archean. This term Archean also found early favor with the Canadian Survey to include these two divisions of pre-Cambrian rocks.

"Eozoic" was another term suggested to replace "Azoic" when many had come to the conclusion that the rocks once supposed to be destitute of life are not really so. This was used to a considerable extent in the sixties and seventies. This term implies a theory just the opposite of "Azoic."

As already said, the theory involved in referring all pre-Cambrian rocks to the "Laurentian" and "Huronian" is that there was in pre-

Cambrian time an invariable succession. This theory was carried to the extreme by Hunt and his school, who held that before Cambrian time there are six rock "systems," which are universal and are separated by unconformities. These are, from the base upward: Laurentian, Norian, Arvonian, Huronian, Montalban, Taconian. Of these terms "Norian" was devised to include the laminated gabbros, the so-called Upper Laurentian of Logan. "Arvonian" was imported from Wales, where it was applied by Hicks to a series of acidic volcanics. "Montalban" came from the White Mountain region in New Hampshire, where a series of gneisses was thought to be of different lithological character from the "Laurentian" and "Huronian" and to overlie them. "Taconian" was introduced by Ebenezer Emmons to cover a series of fossiliferous rocks which was supposed to be earlier than the base of the "Silurian."

Besides the terms given, others have been used to some extent, but they are of little importance. Among these may be mentioned "Hypozoic," "Prozoic," and "Pyrocrystalline."

As the metamorphic theory gained force it became the habit of many geologists to refer to old crystalline or semicrystalline rocks as metamorphic, assuming that they are all produced by the alteration of sediments of some kind. This went so far as to include among the metamorphic sediments perfectly massive rocks, such as diabases, gabbros, granites, etc. Recently the term has also been applied to rocks recognized as laminated eruptives, but this is not the use referred to. The term metamorphic had the advantage of saying nothing as to age or correlation, but in escaping this difficulty another theory was accepted which, so far as its assumption is concerned, was quite as bad.

In many cases local names were applied to formations or groups in order to avoid any theory of age or correlation. The most conspicuous example of this kind is that of the Keweenawan series of Lake Superior.

This tendency to return to the use of local names was plainly a reversion to scientific methods, which were never departed from by certain geologists, who declined to use any term for the ancient rocks which involves a theory of origin or succession, but divided the rocks which they found in their respective districts into lithological divisons or local formations. Conspicuous among early geologists of this class are Jukes, Percival, and Lieber.

In the late eighties Irving proposed that there be placed below the Paleozoic another system of coordinate value, for which the term "Agnotozoic" or "Eparchean" was suggested. This term cut out of the Archean a large class of rocks which had before been included in that system. In 1889 the name Algonkian was brought forward by the United States Geological Survey for the systemic place for which

Irving had proposed "Agnotozoic" or "Eparchean." This involved the restriction of the term Archean to the pre-Algonkian complex. In the previous edition of this bulletin (Bulletin No. 86) Algonkian and Archean were thus used and Proterozoic was favored as the "zoic" term equivalent to Algonkian. Cambrian was defined as extending downward to the base of the beds carrying the *Olenellus* fauna.

In the late nineties work in the Lake Superior region showed that the rocks of the Archean complex are in small part of sedimentary origin. The retention of these sedimentary rocks in the Archean marked a departure from the usage of this term as originally defined by the Survey. The terms as used in the present bulletin are applied essentially to the same rock divisions as before, but the definitions have been modified. The reasons for redefining the terms Archean and Algonkian rather than taking the sedimentary rocks out of the Archean are discussed on pages 19–24.

In 1905 the international geological committee recognized and adopted the following succession and names for the Lake Superior region:

Cambrian: Upper sandstones, etc., of Lake Superior region.
Unconformity.
Pre-Cambrian:
Keweenawan (Nipigon).[a]
Unconformity.
Huronian { Upper (Animikie).
Unconformity.
Middle.
Unconformity.
Lower. }
Unconformity.
Keewatin.
Eruptive contact.
Laurentian.

[a] Lane dissents as to the position of the Keweenawan as follows: "The use of pre-Cambrian above does not imply unanimity in the committee with regard to the pre-Cambrian correlation of the Keweenawan—a topic the committee as such did not investigate."

CHAPTER II.

SUMMARY OF LITERATURE FOR NORTH AMERICA (GENERAL).[a]

MACLURE,[1] [b] in 1809, places in the Primitive rocks granite, gneiss, mica slate, clay slate, primitive limestone, primitive trap, serpentine, porphyry, syenite, topaz rock, quartz rock, primitive flinty slate, primitive gypsum, and white stone; and in the Transition, transition limestone, transition trap, graywacke, transition flinty slate, and transition gypsum. The rocks of the Primitive prevail east of Hudson River. Throughout the greater part of the eastern and northern States the sea washes the Primitive rocks, but to the southwest the Primitive runs in a broad belt as far as Alabama, and between it and the ocean is a wide belt of alluvial rocks. The Transition rocks occur in one main belt, running in a northeast-southwest direction from New York to Alabama, and in several minor belts.

EATON,[2] in 1832, places as Primitive rocks granite, mica slate, hornblende rock, talcose rock, granular quartz, and granular lime rock. These Primitive rocks are all contemporaneous except the granular quartz and lime rocks, since they alternate continually, and all are destitute of organized remains. Numerous localities are given for each class.

EMMONS (E.),[3] in 1855, divides rocks into Pyrocrystalline, Pyroplastic, and Hydroplastic.

The Pyrocrystalline class comprises massive rocks, including granite, syenite, hypersthene, pyrocrystalline limestone, serpentine, rensselaerite, and octahedral iron ore, and laminated rocks, including gneiss, mica slate, hornblende, talcose slate, etc., laminated limestone, and laminated serpentine. The Pyroplastic rocks comprise subaerial, including lavas and tuffs, or volcanic products, and submarine, including greenstone, porphyry, basalt, and trap. The Hydroplastic rocks comprise Paleozoic, Mesozoic, and Cenozoic. The Paleozoic is divided from the base upward into Taconic, Silurian, Devonian, Carboniferous, and Permian. Metamorphic or Azoic rocks are not

[a] This chapter contains only such material as can not be easily classified under the geographic headings of the following chapters. Many articles with references to the general geology of North America have been classed under the local headings.

[b] For notes see end of chapter, p. 104.

recognized as classes, as they may occur in all series from the earliest to the latest sediments. That gneiss, mica slate, hornblende, talcose slate, etc., are metamorphic altered sediments there is no evidence. Azoic is objectionable because it presupposes that our observations have made certain that which must ever remain doubtful.

The Pyrocrystalline rocks are due to the consolidation of the earth's crust. These rocks increase in thickness by additions below. On contraction fissures are formed, through which flow fluid materials which are Hydroplastic and later. The age of rocks may be deduced from the perfection of their crystalline state. The preeminently crystalline granites are the product arising from the first cooling of the first crust. Granite may or may not be connected with the oldest masses of the globe. The granites of the United States are of two classes; those of one class are more ancient than the Taconic rocks; the others, which are later eruptions, are certainly as new as the Carboniferous. In New England the ancient granites are widespread, but there are also large areas of granite which has been erupted from fissures and whose structure is more or less sheeted. It is impossible to draw lines of distinction between the two kinds of granite, except when the earlier granite is traversed by the later. The lamination of the laminated Pyrocrystalline rocks is probably due to crystallization. Gneiss, mica slate, hornblende, and talcose slate are so blended that it is difficult or impossible to define their boundaries, and they are all regarded as contemporaneous formations.

The oldest Hydroplastic rocks constitute the Taconic system, which has a clear and well-defined base, rarely obscured by passages into the primary schists or the Pyroplastic syenites or granites. This system is limited above by the Silurian system, at the base of which is the Potsdam sandstone. The thickness of this system is from 25,000 to 30,000 feet. Sediments of all systems must necessarily consist of the same materials—sandstones, limestones, slates, conglomerates, and breccias; but a comparison of the lower members of the Taconic and the Silurian shows a decided difference in mineral constitution. The first partakes of the primary character of the granite, gneiss, mica, and talcose slates of the Pyrocrystalline rocks, from the last two of which it is often difficult to distinguish them, while the materials of the Silurian are derived from the Taconic rocks. The Taconic system, from the base upward, comprises (1) conglomerates and breccias, (2) limestones, (3) slate of enormous thickness, (4) dark-colored Taconic slates, and (5) sparry limestones. The absence of fossils in the Taconic rocks is thought to be due to the probable absence of animals and plants at the time the Berkshire limestone and earlier Taconic rocks were deposited. In the Upper Taconic rocks are found remains of both plants and animals. The rocks of the Taconic system form a belt on both sides of the Blue Ridge. On the west it is continuous from Canada to Georgia. On the east it is wider in certain places than on the west side, but its continuity is broken. The Taconic system rests, then, on the following points: The formations of the series are physically unlike the Lower Silurian; it supports the Lower Silurian unconformably at numerous places; it is a system in which life existed, and the remains of organisms are unlike those of the Lower Silurian; it carries back many stages farther the time when life appeared, and represents a period vastly longer than the Silurian, although it may occupy a less superficial area.

Logan and Hunt,[4] in 1855, gave a geological sketch of Canada. The ancient rocks are divided into the Laurentian system and the Cambrian and Huronian system.

The rocks of the Laurentian system are almost without exception old sedimentary beds that have become highly crystalline; they have been greatly disturbed, and form mountain ranges running about northeast-southwest, and sometimes rising to heights of 800 or 1,000 meters, and even beyond. The rocks of this formation are the oldest known on the American continent, and probably correspond to the oldest gneisses of Finland and Scandinavia and to similar rocks in the north of Scotland. The rocks of the Laurentian formation are in large part crystalline schists, mostly gneissoid or hornblendic. Associated with these schists are seen heavy stratified masses of a crystalline rock which is almost entirely composed of feldspar with a base of lime and soda. With these schists and these feldspars are found strata of quartzite, associated with crystalline limestones which have a rather important place in this formation. The limestones form beds from 1 meter to more than 100 meters thick, and often present a succession of thin beds intercalated in beds of gneiss or quartzite. The quartzites sometimes present themselves under the form of conglomerates, and in certain cases have a paste of dolomite. Beds of dolomite or of more or less magnesian limestone are often intercalated with pure limestones. These schists, feldspars, quartzites, and limestones, such as we have described them, constitute the stratified part of the Laurentian system; but there are, furthermore, intrusive granites, syenites, and diorites which form quite important masses; the granites are sometimes albitic and often contain tourmaline, mica in large flakes, sphene, and sulphate of molybdenum. Associated with the limestones are important beds of hematite and limonite. Graphite is very frequently disseminated in little flakes in the crystalline limestones, and forms also veins having sometimes a considerable thickness. Two of these are found near Grenville, on the Ottawa. The graphite exists in three detached bands, each having a thickness of about 12 centimeters.

To the Cambrian and Huronian system belong the rocks on the north shores of Lakes Huron and Superior—a series of schists, sandstones, limestones, and conglomerates, interspersed with heavy layers of diorite and resting uncomformably on the Laurentian system. As these rocks are lower than the Silurian terrane, and as they have thus far not yielded a single fossil, they may well be referred to the Cambrian system (the Lower Cambrian of Sedgwick). The schists of this system on Lake Superior are bluish and inclose layers of horn flint having calcareous bands and cracks often filled with anthracite. These rocks are covered with a considerable thickness of trap, on which are superposed heavy beds of white and red sandstone, which sometimes pass into a state of conglomerate inclosing globes of quartz and jasper. Beds of a reddish argillaceous limestone are found interspersed with these sandstones, which are cut through and covered by a second formation of diorite of great thickness, offering a columnar structure. This formation, which has a total thickness of nearly 4,000 meters, is traversed by a great number of trap dikes. In the corresponding formation of the north shore of Lake Huron are found sandstones having a more vitreous aspect, and conglomerates more abundant than on Lake Superior, associated, however, with schists and schistose conglomerates resembling those just described, the whole presenting great masses intercalated with diorite. A layer of limestone having a thickness of 16 meters forms part of this series. After the eruption of the interstratified diorites have appeared two systems of dikes of diorite, and a third of granite, of an epoch intermediate between the other two. The formation of the metalliferous veins belongs to an epoch still more recent.

This Huronian formation is observed over a distance of nearly 150 leagues on Lakes Huron and Superior.

Dana,[5] in 1863, gives an account of the Azoic age. This age is defined as the age in the earth's history preceding the appearance of animal life. Among the Azoic rocks are included all the rocks that are older than the Potsdam sandstone of New York, between which and the Azoic general unconformable relations obtain. The Azoic rocks constitute the only universal formation. They cover the whole globe, and were the floor of the oceans and the rocks of all emerged land when animal life was first created. But subsequent operations over the sphere have buried the larger part of the ancient surface, and to a great extent worn away and worked up anew its material, so that the area of the old floor now exposed to view is small. The Azoic regions include Canada north of the St. Lawrence, reaching northeast from Lakes Huron and Superior to Labrador, and continuing northwest to the Arctic Ocean, the Adirondacks of northern New York, a similar area south of Lake Superior, west of the Mississippi a small area in Missouri, the Black Hills in Dakota, the Laramie Range in

Nebraska, part of the Ozark Mountains in Arkansas, and in northern New Jersey Azoic gneiss, limestone, and other crystalline rocks containing beds of iron ore. The rocks of the Azoic are mostly of the metamorphic series, related to granite, gneiss, syenite, and the like, but they embrace only the most ancient of these rocks. The Azoic rocks are nearly all crystalline, a few sandstones, slates, and conglomerates being the only exceptions. They are remarkable for the small amount of silica they contain, as shown in the diorites and labradorite rocks. Prevalence of iron ore is another characteristic, and none of the minerals are simple silicates of aluminum. While the Azoic rocks are crystalline they follow one another in variations and alternations, like sedimentary beds of later date. Granite or gneiss may lie between layers of slate or schist, and quartz rock may have any place in the series. The Azoic rocks are the results of alteration of sedimentary strata, as is shown by the fact that schists graduate into true slates, quartzites into sandstones, and conglomerates and gneiss into gneissoid granite and thence to true granite and syenite. As evidence of life in the Azoic age are cited the formations of limestone strata, the occurrence of graphite in the limestone, and the occurrence of anthracite in small pieces in the iron-bearing rocks of Arendal, Norway. Crystalline rocks have been formed in various ages, those in New England, for instance, long after the Azoic; hence it is possible that some of the Azoic rocks have undergone a second or third alteration subsequent to the original one in the Azoic age.

Logan,[6] in 1864, gives a general account of the ancient rocks of Canada. He states that the rocks composing the Laurentide Mountains in Canada and the Adirondacks in New York are the oldest in North America. They have been shown to be a great series of strata which, though profoundly altered, consist chiefly of quartzose, aluminous, and argillaceous rocks, like the sedimentary deposits of less ancient times. This great mass of crystalline rocks is divided into two groups, and it appears that the Upper (Labradorian) rests unconformably upon the Lower (Laurentian) series. The united thickness of these two groups in Canada can not be less than, and probably much exceeds, 30,000 feet. A third Canadian group, the Huronian, has been shown by Murray to be about 18,000 feet thick, and to consist chiefly of quartzites, slate conglomerates, diorites, and limestones. The horizontal strata, which form the base of the Lower Silurian in western Canada, rest upon the upturned edges of the Huronian series, which, in its turn, unconformably overlies the Lower Laurentian. The Huronian is believed to be more recent than the Upper Laurentian series, although the two formations have never yet been seen in contact.

The united thickness of these three great series may possibly far surpass that of all the succeeding rocks, from the base of the Paleozoic series to the present time. We are thus carried back to a period so remote that the appearance of the so-called Primordial fauna may be considered a comparatively modern event. We, however, find that, even during the Laurentian period, the same chemical and mechanical processes which have ever since been at work disintegrating and reconstructing the earth's crust were in operation. In the conglomerates of the Huronian series there are inclosed bowlders derived from the Laurentian, which seem to show that the parent rock was altered to its present crystalline condition before the deposition of the newer formation, while interstratified with the Laurentian limestones are beds of conglomerate, the pebbles of which are themselves rolled fragments of still older laminated sand rock, and the formation of these beds leads us still further into the past.

In both the Upper and the Lower Laurentian series there are several zones of limestone, each of sufficient volume to constitute an independent formation. Of these calcareous masses it has been ascertained that three, at least, belong to the Lower Laurentian. But as we do not as yet know with certainty either the base or the summit of this series, these three may be conformably followed by many more. Although the Lower and Upper Laurentian rocks spread over more than 200,000 square miles in Canada, only about 1,500 square miles have yet been fully and connectedly examined in any one district, and it is still impossible to say whether the numerous exposures of Laurentian limestone met with in other parts of the province are equivalent to any of the three zones, or whether they overlie or underlie them all. As evidence of life in the Laurentian limestone are graphite, great beds of iron ore, and recognizable organic forms resembling Stromatopora.

HUNT,[7] in 1867, again characterizes the Laurentian and Huronian rocks.

Under the name Laurentian terrane, the Geological Commission of Canada at first comprehended two distinct series of rocks, one resting unconformably on the other, which it afterward distinguished as Lower Laurentian and Upper Laurentian or Labradorian. The first of these two series corresponds to the Primitive gneiss (Urgneiss) of Scandinavia and of the west coast of Scotland. After carefully studying this ancient gneissic system of North America, the Geological Commission of Canada gave it the name of Laurentian system, taken from the Laurentide Mountains. As early as 1855 the conviction was expressed that it is identical with the Primitive gneiss of European countries, an identity which afterward was established by Murchison for Scotland. More recently Gumbel and Von Hochstetter, after an exhaustive study of the old gneiss of Bavaria and Bohemia, enunciated its identity with the Laurentian terrane of Canada, a conclusion which the former of these scientists, moreover, supported by a comparison of the organic remains of the two regions.

The Lower Laurentian is composed of crystalline schists, a large part of which are gneisses, at times granitoid, with quartzites, often conglomerates; amphibolic and micaceous schists, pyroxenic rocks, ophiolites, and limestones, sometimes magnesian. These limestones, ordinarily very crystalline, are found united in three great distinct formations, each having a mean volume of 1,000 to 1,500 feet, and separated by still more considerable masses of gneiss and quartzite. The measured thickness of this series on the Ottawa exceeds 20,000 feet, which is probably far from representing the total volume of the system, which in Bavaria is supposed to attain not less than 90,000 feet. In Hastings County, north of Lake Ontario, there is found resting conformably on Laurentian gneiss a series of at least 20,000 feet of crystalline schists, comprising a great thickness of impure limestones and calcareous schists, and terminating in a heavy mass of dioritic rocks. It seems established that this series, which differs sensibly by the succession of the beds and by its lithological characters from that described above, belongs also to the Lower Laurentian, of which it would form a higher member; and thus the known thickness of this system in Canada would rise to at least 40,000 feet.

The Upper Laurentian or Labradorian terrane is found resting, in the form of patches, unconformably on the Lower Laurentian, both on the Hastings series and on the Ottawa series, where it often occupies a width of several miles. It is found at intervals from Lake Huron to the coasts of Labrador, and is everywhere recognized by its lithological characters. This Labradorian terrane inclosed gneiss with orthose, with quartzites and crystalline limestones, but its predominating element is an anorthosite, or rock composed essentially of a feldspar of the sixth system, with a mixture of pyroxene, often assuming the form of hypersthene. This anorthosite is sometimes gneissoid, and even fine grained; but it assumes rather often a granitoid structure, with great cleavable forms in the feldspar. The latter is ordinarily andesite or labradorite, of which it sometimes presents fine opalescent varieties resembling those brought from Labrador. The thickness attained by the Upper Laurentian terrane is not certain, but it probably exceeds 10,000 feet. The Lower Laurentian presents nothing that resembles the anorthosites of the Upper Laurentian, which form the highest summits of the Adirondacks, and seems to be identical with the hypersthenites of the Hebrides of Scotland, described by MacCulloch. The limestones of the Lower Laurentian of Canada inclose organic remains, principally belonging to an organism studied and described by Dawson, who has given it the name *Eozoon canadense*.

The Lower Laurentian terrane is affected by many undulations that have upraised the beds, rendering them at times almost vertical. The mean direction of these foldings is about north and south, but secondary undulations from east to west appear in the region north of the Ottawa, the only one where thus far it has been possible to study the intimate structure of this terrane. The beds of the Upper Laurentian also are upraised at high angles, but the structure of this terrane, which has evidently undergone part of the movements that affected the lower, has not yet been studied. The lower terrane is traversed in several localities by igneous rocks, and there have been ascertained at least four epochs of effusion, three of which are anterior to the Silurian period. These eruptive rocks are syenites, quartziferous porphyries, and dolerites.

Under the name Huronian terrane is designated a series of rocks, more or less altered, resting unconformably on the Lower Laurentian terrane, and probably also on the Labradorian terrane. This series is composed of quartzites, more or less chloritic or epidotic schists, sometimes with impure serpentines, and diorites, which constitute very important masses in the series. The quartzites, as well as the chloritic schists, often inclose rolled pebbles, many of which are derived from the Laurentian gneiss. This Huronian terrane comprises, moreover, a band of about 300 feet of granular limestone, which is impure and often very siliceous. The Huronian terrane on Lake Huron has a thickness of about 18,000 feet. It is also found on the Ottawa, and thence extends to the west of the Mississippi, though covered in large part by Paleozoic terranes. It does not seem to exist in the eastern region of Canada, but recent observations made on the island of Newfoundland and in Nova Scotia have demonstrated the existence there of rocks that have been referred to this old terrane which seem to correspond to the Primitive schists (Urschiefer) of Scandinavia. No fossils have yet been found in this terrane. Considerable masses of schistose hematitic iron ore are inclosed in this Huronian terrane on the northeast shore of Lake Superior, and in still greater abundance at the south, where the famous iron mines of Marquette are found. This terrane is more or less affected by undulations anterior to the Silurian epoch.

DANA,[8] in 1872, states that lithological evidence for the chronological arrangement of the crystalline rocks of New England means nothing until tested by thorough stratigraphical investigation. This evidence probably means something with respect to Laurentian rocks, but it did not until the age of the rocks, in their relations to others, was stratigraphically ascertained. It may be worth something as regards later rocks when the facts have been carefully tested by stratigraphy. Before a fossil is used for identifying equivalent beds it is by careful observation proved to be restricted to the rocks of a certain period, and even then it is used cautiously. Has anyone proved by careful observations that crystals of staurolite, cyanite, or andalusite are restricted to rocks of a certain geological period?

DANA,[9] in 1876, gives an account of Archean time. The Archean time includes an Azoic and an Eozoic era, though not yet distinguished in the rock. The Azoic age is the era in which the physical conditions were incompatible with the existence of life. But this era, so far as now known, is without recognizable records; for no rocks have yet been shown to be earlier in date than those which are now supposed to have been formed since life began. The Archean rocks of North America are mostly crystalline or metamorphic rocks, and their beds stand at all angles, owing to the uplifting and flexing which they have undergone. Where the Silurian strata overlie them the two are unconformable, the latter being often spread out in horizontal beds over the upturned edges of the Archean rocks.

The areas of the Archean include those which have always remained uncovered, those which have been covered by later strata but from which the superimposed beds have been removed by erosion, and those like the last which in the course of mountain making have been pushed upward among the displaced strata. The principal areas are the great northern, to which belong the Lake Superior region and properly the Adirondack area; the area along the Appalachian line, including the Highlands of New York and New Jersey and the Blue Ridge of Pennsylvania and Virginia; the Atlantic coast range, including areas in Newfoundland, Nova Scotia, and eastern New England; isolated areas of the Mississippi basin, in Missouri, Arkansas, Texas, and the Black Hills; the Rocky Mountain series, embracing the Wind River, Laramie, and other summit ranges, and the Pacific coast range of Mexico.

The Archean era is divided into two periods, the Laurentian and the Huronian. The estimated thickness of the former is 30,000 feet, and of the latter from 10,000 to 20,000 feet. The Laurentian rocks are metamorphic or crystalline, with few exceptions, and include granite, gneiss, mica schist, hornblende, and pyroxenic rocks, beds of crystalline limestone, quartzite, conglomerate, and labradorite. The Laurentian beds are altered sedimentary rocks of the ordinary character, as the schists grade into true slates, the quartzites into sandstones, and conglomerates and gneisses into gneissoid granites. No distinct remains of plants have been observed. Graphite is very abundant. Only the lowest division of animal life, such as the rhizopods and protozoans, occur. This is shown by the occurrence of the fossil *Eozoon canadense*. The Huronian includes the series on the north shore of Lake Huron composed of slates, conglomerates, quartzites, layers of jasper, and chert, with quartz and jasper conglomerates, limestones, and beds of diorite which graduate into syenite or epidote, and also other areas which have been placed as the equivalent of this series on lithological grounds.

KING,[10] in 1878, states that in the Archean outcrops of the fortieth parallel one can not fail to notice the widespread simplicity of petrological forms, the prevalence of granites, granitoid gneisses, and dioritic metamorphic rocks, the paucity of argillites, quartzites, limestones, and zirconiferous and staurolitic schists, the infrequence of large bodies of magnetic, specular, or spathic iron, and the complete absence of corundum, chrysolite, serpentine, steatite, pyroxene rocks, the true nacreous schists, and other minor forms observed in the Appalachian system.

Without doubt, the most interesting facts which the comparison of these exposures discloses are: When considered in depth, from the uppermost limits of our so-called Huronian to the lowest Laurentian exposure, there is, first, a regular, steady increase of the intensity of metamorphism, and, second, a pretty regular increase in the thickness of individual members of the series. The lowest Laurentian aplitic granitoid bodies of the Laramie Hills are the heaviest beds and the most changed from their original sedimentary condition. The higher Huronian group of gneisses, quartzites, conglomerates, dolomites, and argillites are at once the most thinly bedded and least metamorphosed. Individual beds remain as specialized as the day they were deposited. At the lower exposures of the whole Archean formation well-defined crystals are of great rarity; even microscopic apatite, the best presented species, is generally crushed and dislocated; micas are distorted, and all feldspars are more or less fragmentary. A marked contrast is observable at the upper extreme; here many micas, hornblendes, garnets, and even feldspars are nearly, if not quite, completed crystals. The exceptions to this are those places, already described, where local compression has broken up the original arrangement of the crystalline ingredients.

Nearly every considerable mountain body between the Wasatch and the California line shows in the lowest horizons exposures of one or more bodies of granite. These are classified into four groups on petrological grounds. The first type consists of quartz, orthoclase, an unimportant amount of plagioclase, and muscovite, with a small quantity of microscopic apatite. These are all west of Reese River, longitude 117°. They are all associated with the Nevada type of Archean crystalline schists, composed of quartz, biotite, muscovite, and magnetite, or quartz, hornblende, and magnetite. As to the age of the granites of this type there are practically no data available. At one place it is intimately involved with the crystalline schists and is overlain unconformably by the Carboniferous. There is little doubt that it is Archean, but its reference to that period is on general lithological grounds. The second type is of the same composition as the first, except that biotite is substituted for muscovite. It has a range from the Ombe Mountains west of Salt Lake Desert to the California line. The third type is like the second except that biotite and hornblende are found together. This distribution is coextensive with that of the second type. The fourth type is the most complex in its petrological features of all the families of granite, and consists of quartz, orthoclase, plagioclase, often equal in quantity to the orthoclase and sometimes exceeding it, usually a high percentage of biotite and hornblende, titanite, and a high proportion of microscopic apatite. Between this class and the diorites that are unusually rich in orthoclase there is but little difference, although there is little danger of ever confounding the granitoid diorite with the dioritic members of the fourth type. These granites are the most prominent as regards geographical distribution of the truly eruptive varieties observed in the Cordilleras. When the different types of granite are seen in apposition, so as to give a clue to their relative ages, it is found that they occur in the order given. In denominating these groups of granite as eruptive it is only intended to indicate that in their relations to the contiguous Archean schists they have the appearance of intrusive bodies, and that in their interior structure and general mode of occurrence there are none of those evidences of alliance to the crystalline schists which are observed in the granitoid gneisses of so many localities, especially in the Rocky Mountain region. In so-called eruptive granites there is parallelism neither of general bedding nor of interior arrangement of the minerals, and the most ordinary phenomenon of structure is the development of conoidal shapes formed of concentric layers varying in thickness from a few inches to 100 feet. This structure, so far as observed, is strictly confined to the hornblende-bearing granites, and never makes its appearance in those of the first and second types. Although instances of each type of granitic rock are found unconformably underlying the low members of the Paleozoic series, this is not the case with each outcrop; many granitic masses are found unconformably underlying Mesozoic or even Tertiary volcanic rocks. But there is absolutely no evidence whatever in favor of the belief of granitic extrusions later than the Archean age. Although Whitney has found intrusions of granite in sedimentary strata other than the Archean crystalline schists, any attempt to correlate age by petrological features alone is dangerous, as may be shown by the fact that the Jurassic granite of California and the granite of the Cottonwood region on the Wasatch, which is unmistakably Archean, are positively identical down to the minutest microscopical peculiarity.

In the crystalline schists and gneisses are found identically the same minerals which characterize the granites. In the schists the characteristic feature is the parallel bedded arrangement. Granite possesses the same minerals; the sole difference seems to be that granite is often demonstrably a plastic intrusion and possesses no parallel arrangement of minerals. The geognostic position of the schists is exactly like that of the other strata which were deposited horizontally and afterward disturbed. On the other hand, granite in an immense majority of cases is found exposed in the hearts of the mountain ranges. It is only when we can observe granite in direct connection with the strata into which it has intruded or out of which it has been made that the true relations can be seen; and it is safe to say that wherever these intimate relations are observable the granite occupies a region which has been subjected to horizontal or circumferential pressure. The frequent phenomena of the underdip of the strata flanking a granite mass, as in the great granite body of the Sierra Nevada, are prominent instances of the intimate relation spoken of. If in such cases an unconformable overlying and unaltered series were to cover all but the summits of the granite hills, the granite would appear simply as an unconformable underlying body whose genetic relations are absolutely unknown. In this category a vast number of granite exposures of the Cordilleras have to be placed.

It is an invariable law, then, that where the genetic relations are clearly perceived eruptive granite is always found in connection with very great horizontal pressure and consequent disturbance. Suppose, now, a deep-lying series of varied sedimentary beds, covered by a sufficient superimposed mass to exert a pressure powerful enough to sink them to the necessary thermal horizon for the induction of crystallization in the material of the beds. As long as the attitude of these beds was undisturbed by horizontal compression the result would be a series of crystalline schists and gneisses. But the moment horizontal or tangential pressure either overcame or disturbed the action of the downward pressure, the horizontal arrangement of these crystallizing materials would be broken up, and their resulting arrangement would depend upon the interaction of the two forces.

SELWYN,[11] in 1879, proposes the following general stratigraphy for the older rocks: I. Laurentian: To be confined to all those clearly lower unconformable granitoid or syenitic gneisses in which we never find interstratified bands of calcareous, argillaceous, arenaceous, and conglomeratic rocks. II. Huronian: To include (1) the typical or original Huronian of Lake Superior and the conformably—or unconformably, as the case may be—overlying upper copper-bearing rocks; (2) the Hastings, Templeton, Buckingham, Grenville, and Rawdon crystalline limestone series; (3) the supposed Upper Laurentian or Norian; (4) the altered Quebec group and certain areas not yet defined between Lake Matapedia and Cape Maquereau, in Gaspe; (5) the Cape Breton, Nova Scotia, and New Brunswick pre-Primordial subcrystalline and gneissoid groups. III. Cambrian: In many of the areas, especially the western ones, the base of this is well defined by unconformity, but in the Eastern Townships and in some parts of Nova Scotia it has yet to be determined. The limit between it and Lower Silurian is debatable ground. One point is particularly insisted on, that great local unconformities and lithological differences may exist without indicating any important difference in age, especially in regions of mixed volcanic and sedimentary strata, and that the fact of crystalline rocks (greenstones, diorites, dolerites, felsites, norites, etc.) appearing as stratified masses and passing into schistose rocks is no proof of their not being of eruptive or volcanic origin; their present metamorphic or altered character is, as the name implies, a secondary phase of their existence, and is unconnected with their origin or original formation at the surface, but is due partly to original differences of composition and partly to the varying physical accidents to which they have since their formation been subjected.

SELWYN,[12] in 1881, states that the anorthosite rocks are in general conformity with the crystalline limestones, but are occasionally interfered with and disturbed by intrusions (?) of the more massive and granitoid variety of labradorite. This is proof that the labradorite or Norian rocks of Hunt do not constitute an unconformable Upper Laurentian formation, but occur in part as unstratified intrusive masses and in part as interstratifications with the orthoclase gneisses, quartzites, and limestones of the Laurentian system, as developed in the Grenville region and mapped by Logan.

As to the granites which have been regarded as intrusive by Logan, in both the crystalline and the fossiliferous rock, there is no doubt that they are of later origin than the Silurian rocks which surround them and which are everywhere, on approaching the granite, considerably altered, chiastolite, andalusite, garnet, mica, and other minerals appearing in the slates, which are also occasionally changed to quartzose or feldspathic mica schists, and the associated fossiliferous limestone to crystalline and micaceous dolomites, with the fossils still perfectly distinct. It has been customary and orthodox to regard these granites as "intrusive," and they are so designated by Logan. The author holds that there is absolutely no proof of their being so, either in the Eastern Townships, in Nova Scotia, or in Australia, and that all the phenomena connected with them may be more readily explained and understood if we regard them as completely metamorphosed portions of the strata which now surround them; while the mere displacement of strata involved in the intrusive theory appears, in view of the enormous area now occupied by the granite, wholly inexplicable, as does also the manner in which the surrounding strata often dip down against and onto the granite and show no signs of having been deflected or otherwise affected as regards strike and dip by the supposed intrusions.

There is, however, often seen along the contact lines of the granite and the slates a considerable breaking up and crushing of the latter, and this has been held to indicate and be the result of the intrusion of the granite. It appears to be mainly due to the unequal resistance that the two rock masses have offered to the disturbing forces of upheaval, depression, and consequent pressure which have repeatedly affected them long after the formation of the granite. The effect thus produced is analogous to that which occurs where the forces producing slaty cleavage encounter interstratified hard layers of sandstone, when the elsewhere perfectly regular and parallel cleavage planes are immediately crushed, crumpled, and deflected.

In regions where the granite or other hard crystalline rock is older than the adjacent or alternating softer strata, perfectly similar contact lines may be seen, but unaccompanied by any change in the mineralogical character of the adjacent strata, such as occurs when the crystalline rock is the youngest; and therefore this phenomenon can not be taken as conclusive evidence of the intrusive origin of granite or other crystalline rock.

SELWYN,[13] in 1883, remarks that the Devonian granite-forming epoch has had immense influence in the pre-Carboniferous rocks of the region to the southeast of the great St. Lawrence, Champlain, and Hudson River break. This is certainly deserving of more careful consideration and study than it has yet received, and more especially so in connection with the alteration and metamorphism it has produced in large areas of Paleozoic and perhaps pre-Paleozoic rocks. When these altered Paleozoic strata come in contact, as they often do in eastern Canada and in New England, with the more ancient Huronian and Laurentian gneiss, granite, mica schist, and other crystalline rocks, it is possible to distinguish them or to define their respective limits only by the most careful and minute stratigraphical work, such as the nature of the regions in New England and in the adjacent provinces of Canada, where these rocks are chiefly developed, renders almost impossible—at any rate, it has never yet been attempted. Hence the maps hitherto published, representing the geological structure of these regions, have necessarily been based almost entirely, so far as the crystalline groups are concerned, on lithological and mineralogical comparisons and considerations, producing petrological rather than geological maps, and as a consequence, though important and valuable aids to future investigation, they afford a very incorrect and imperfect idea of the true geological structure and the sequence and distribution of the several formations. Unfortunately, while careful, patient, and minute observation in the field has been unavoidably limited and local, study in the laboratory and theoretical deductions therefrom have been unlimited and widespread, but, as might have been expected, have not only afforded no satisfactory solution of the intricacies of Appalachian geological structure, but have, on the contrary, involved it in deeper mystery and complication. It is now evident that an entirely different system of procedure must be adopted before there will be any hope of definitely and satisfactorily solving the problems which have been presenting themselves to successive observers in this difficult field.

Selwyn and Dawson,[14] in 1884, state that recent investigation has greatly enlarged the area over which the Archean rocks are known to extend, though it has not yet afforded any more satisfactory evidence of the relations of the Huronian rocks to the Laurentian. In all cases the supposed junction of the strata of the two systems either shows them vertically side by side or the Huronian strata apparently dipping under the Laurentian, while both present a very constant northeasterly strike. Notwithstanding these facts, their exceedingly different mineralogical characters and general appearance, broadly viewed, render it almost impossible to suppose that the superposition, as indicated by these dips, is the true one or that the Huronian is not newer than the Laurentian. If so, we must admit that both systems are presented in a constant succession of enormously thick overturned folds, with perhaps many dislocations and slips on the lines of the anticlinal axes.

As regards the so-called Norian or Upper Laurentian formation, the writers have no hesitation in asserting that it has, as such, no existence in Canada, its theoretical birthplace. Wherever these Norian rocks have been observed either they are intimately and conformably associated with the ordinary orthoclase or pyroxenic gneisses or they occur as intrusive masses, when they present no gneissic or bedded structure. They clearly cut the surrounding gneiss, and are probably due to volcanic or other igneous agency in the Laurentian age. Such masses may not unreasonably be supposed to mark the sites of the Laurentian volcanoes, while the bedded labradoritic gneisses and other associated strata may with equal probability represent the eruptive rocks—lava flows, etc.—which emanated from them and were locally interbedded with the ordinary sediments of the period, as rocks of similar origin and composition certainly were in the Huronian and in all later geological ages, a fact which has been singularly overlooked or ignored by most writers on American geology.

At present we have in Canada no evidence which would warrant us in making more than two great divisions in the Archean crystalline rocks. In many parts, especially in the eastern provinces, it has been found impossible to define even these clearly. Rocks of typical Laurentian character are there so intimately associated with others of equally typical Huronian characters, and the two kinds are in such constant alternation, that in mapping them they could not be separated, and are therefore all classed as Archean or pre-Cambrian.

WHITNEY and WADSWORTH,[15] in 1884, after a very wide but disproportionate review of the literature of the pre-Potsdam rocks, conclude that it is impossible for any unprejudiced worker in this department of science to peruse with care the pages given and not be obliged to admit that the geology of a large portion of this country, and especially that of Canada and New England, is in an almost hopeless state of confusion. The belief is justified that our chances of having at some future time a clear understanding of the geological structure of northeastern North America would be decidedly improved if all that were written about it were at once struck out of existence. While not desiring to conceal the fact that some of the problems presented in the course of the study of the older rocks are extremely difficult, it is clearly proved that want of knowledge, want of experience, and a desire to produce sensational theories have brought about this condition of confusion.

In reference to Azoic rocks, there are several classes to which this term may be applied. First, it may be applied to strata once fossiliferous in which the evidences of life have disappeared. Second, rocks may be azoic even if laid down when life was existing on the globe, provided the local conditions were not favorable to its development at the particular locality under consideration. Third, rocks must necessarily be azoic when formed or originating under conditions incompatible with the existence of life. Such was the original crust of the earth and the volcanic eruptive rocks. Fourth, we may have rocks formed under such conditions as were not inimical to life, but yet azoic, because life had not begun to exist on the globe at the time of their deposition. These, according to our view, would be the rocks properly designated by the term Azoic, and the body of rocks having this character might properly be called the Azoic system. And we think that, in view of what has here been set forth, no one will deny that it is important that, if there are such rocks, they should have a special designation, and that the term Azoic would be a proper one to apply to them.

This, however, is exactly what was done by Foster and Whitney in 1850, when they gave the name Azoic system to a body of strata, originally—in part, at least—of sedimentary origin, which did not show by their character that life could not have existed at the time of their deposition, but which proved, on examination, to be entirely destitute of fossils, and which, moreover, were found everywhere to underlie unconformably other stratified formations which were recognized as containing the lowest known forms of organic life.

It is denied that *Eozoon*, beds of limestone, the presence of graphite in crystalline limestone, or any other discovered material in the pre-Potsdam rocks is sufficient evidence for the presence of life.

It is considered that we are fully justified in saying that the results of geological investigation during the last thirty-five years have given no encouragement to the idea that below the well-known Primordial zone—the Potsdam sandstone of American geologists—there is another series of fossiliferous rocks.

If the Azoic rocks are really azoic, as is believed, then it follows, as a matter of course, that the series thus designated can be separated into subsystems only on purely lithological grounds; if they are fossiliferous, as held by the Canada Survey, it is equally clear that any subdivisions proposed for them should have a paleontological basis. It is denied that *Aspidella* and *Arenicolites spiralis* are of organic origin.

If we examine the often repeated statement that the Huronian unconformably reposes on the worn edges of the Laurentian and contains the débris of the latter, it will be found that in the seven cases in which the rocks referred to these two formations were found in contact in the Canadian district the Huronian, with but two exceptions, is said to be conformable with and to generally pass imperceptibly into the Laurentian. In one of these two exceptions the rocks show mutually intrusive relations, and in the other the Huronian abuts against and runs under the Laurentian.

In all cases in which pebbles and fragments of the Laurentian have been found in the Huronian they were seen occurring high up in the latter series, and not forming basement conglomerates. All the other so-called proof of unconformity has been made out of the fact that the strike of the foliation in the two formations, when not in contact, has been found to be discordant—worthless evidence unless the rocks observed in both formations be proved to be sedimentary and the foliation be shown to be coincident with the stratification. Now, if the Laurentian was an old metamorphosed sedimentary formation which had been upheaved and contorted, and on whose worn edges the Huronian was laid down, the evidence of the fact ought to be overwhelming in amount after the country has been studied for so many years.

It is well known that any eruptive rock so soon as it comes in contact with erosive agencies will yield fragmental material, even before it is cold, and that much eruptive matter is ejected in a fragmental state, so that in a mixed series of eruptive and detrital rocks nothing is more common than to have the débris of one inclosed in another, without that inclosure proving that the rocks differ in geological age. This is well known to be the case with the copper-bearing rocks of Keweenaw Point, and it has been shown that the iron ores of the

Marquette district, which form a constituent part of the so-called Huronian, are overlain by a conglomerate containing the débris of the former; yet both are by every geologist placed in the same series.

The basis of fact which forms the main support of the twofold division of the Archean—including under that designation all rocks lying below the lowest fossiliferous series—is this: The axial or eruptive portions of disturbed and mountain regions are largely granitic and gneissoid in character. These granitic, granitoid, and gneissic masses are brought to light in the cores of great mountain chains, where long-continued uplift of the original crust of the earth has, through a succession of geological ages, been furnishing the material from which the sedimentary formations were built up. That the gneissic or gneissoid rocks are closely allied to the distinctly granitic and not necessarily metamorphosed stratified deposits is clear, as the result of long-continued investigations in regions where rocks of this kind occur. Not that all gneisses are of this character; but those are ordinarily so which with granite make up the axial masses of disturbed regions. That the parallel structure of the materials forming gneiss is not necessarily the result of sedimentation seems clearly to result from that which has been done in both experimental and field geology within the last few years. It can not be denied that a foliated arrangement or a parallel disposition of the mineral elements of various sedimentary rocks can be, and often has been, induced in them after their deposition, and that this parallel arrangement is not by any means necessarily coincident with the planes of stratification. This fact alone is absolutely conclusive in favor of the idea that parallel arrangement of the mineral constituents of a rock—in other words, a gneissic structure, in rocks of the granite family—is not proof of sedimentation.

Overlying the granitic and gneissic axial rocks we are likely to find, and in many cases do find, the stratified masses which were formed from the preexisting crust themselves usually highly metamorphosed, because formed at a period of great chemical and mechanical activity. With these stratified and highly altered masses are associated eruptive materials—both interbedded and injected in dike form—these also often greatly metamorphosed, and to such an extent that their original character is only with difficulty, and with the aid of the microscope, to be recognized. This protrusion or forcing out of eruptive materials seems to have followed the preceding uplift of the original crust, if not as a necessity at least as something extremely likely to occur, as is shown by the fact that in so many great mountain chains we find volcanic activity more and more predominating with the progress of geological time. Since these eruptive materials come from a gradually increasing depth below the surface of the original crust they are more basic than this, and, since as a rule they contain more iron than that crust, are darker colored than the masses by which they are directly underlain. Hence the detrital beds formed from the débris of these more basic materials are themselves of a dark color, and as a result of their metamorphism we have the various slates, argillaceous, talcose, and chloritic, which so commonly rest upon the granitic and gneissoid rocks that form the core or axis of the disturbed region. With these slaty rocks are also associated limestone masses, which, so far as our observations go, are not ordinarily interstratified with the slates, but are of the nature of segregated deposits, having been formed posterior to the formation of the sedimentary beds with which they are associated, while the metamorphosing agencies were at work making over the beds into the crystalline form in which we now see them.

In the division of the rocks into Laurentian, Huronian, Norian, Montalban, Taconian, and Arvonian only lithological principles are now used, and every fact pertaining to the origin and relations of these rocks is ignored; and since, while it is assumed that all these rocks are sedimentary, they are found to occur in dikes and other eruptive forms, it becomes necessary to hold that all eruptive (including volcanic) rocks were the products of a metamorphic (aqueo-igneous) action. Hence it is claimed that all these rocks had been deeply buried and then denuded, and most extravagant views have become current regarding denudation.

It thus came about that the coarser grained granitoid and gneissic rocks were set apart as Laurentian; the gabbros and some of the more coarsely crystalline diabases and diorites were erected into the Norian; the felsites and quartz porphyries were placed as the Arvonian; the finer grained diorites, diabases, melaphyres, and chlorite schists were formed into the Huronian; the more friable granitic and gneissic rocks, with the mica schists, were classed as Montalban; and the quartzites, limestones, and argillites were united into the Taconian. Of course, in each case the metamorphic fragmental forms of each rock were placed with the rocks they resembled, while the other forms of crystalline rocks were distributed through the groups.

Adams,[16] in 1887, gives a general consideration of the Upper Laurentian or Norian, which has been separated from the Lower Laurentian by the predominance of plagioclase feldspar. These rocks occur in detached areas in the Laurentian districts and are similar to the gabbro and gabbro-diorites of Scandinavia. At least nine areas are known to exist in Canada, and one in New York. Besides pyroxene and plagioclase, many other minerals are found.

The rocks show much variation in structure. They are rarely quite massive, frequently well foliated, but usually consist of a rather coarsely crystalline groundmass through which are scattered irregular strings and masses composed of iron ore, bisilicates, and mica, as well as larger porphyritic crystals of plagioclase. Even when tolerably constant in composition there is generally a great variation in size of grain, coarse and fine layers alternating in rude bands or rounded masses. In the case of some of the areas there can be but little doubt that the anorthosite is eruptive; in others, however, it seems to be interstratified with the Laurentian gneiss, and in one of them to merge imperceptibly into it. The original relations of the rocks are, of course, much obscured by the effects of subsequent heat and pressure. The evidence at present, however, seems to indicate that the anorthosites are the result of some kind of extravasation which in early times corresponded to what in modern times we call volcanic eruption.

DAWSON (Sir WILLIAM),[17] in 1888, describes the Eozoic rocks of the Atlantic coast and compares them with those of western Europe and the interior of America.

The Laurentian system consists in all parts of the world largely of orthoclase gneiss associated with crystalline schists, and locally quartzites and limestone.

No one who has studied the typical districts of Ottawa River can doubt for a moment that they are regularly bedded deposits, and that in the Middle Laurentian those conditions which in later periods have produced beds of limestone, sandstone, iron ore, and even of coal, were already in operation on a gigantic scale. At the same time it may be admitted that some areas of the lower gneiss may be cooled portions of an original igneous mass, and that many of the schistose rocks may be really bedded igneous materials.

Laurentian rocks compose the nucleus of the island of Newfoundland and occur in Cape Breton and in southern New Brunswick.

In the typical area of Lake Huron, as originally described by Logan and Murray, the Huronian rests unconformably on the Lower and Middle Laurentian, and presents a great contrast in point of mineral character to these formations. It is comparatively little disturbed, and is clastic rather than crystalline in character. This point has been well insisted upon by Bonney and by Irving in recent papers. Further, its conglomerates contain pebbles of Laurentian rock in the same crystalline state in which these rocks are found at present. It consists chiefly of quartzites, conglomerates of different kinds, limestone, and slates, sometimes chloritic, with interbedded diorite.

In Newfoundland the older slate series of Jukes is lithologically very like the Huronian, and this likeness is increased by the fact that red sandstones and conglomerates like the Keweenian of the West overlie these lower slates.

On the coast of southern New Brunswick are the Coldbrook and Coastal series, essentially like those of Newfoundland. The Coastal group may perhaps be of later age than the Huronian proper, although pre-Cambrian.

As in Newfoundland, the typical Huronian of New Brunswick is overlain by conglomerates, sandstones, and shales. The Huronian rocks of Huron, Newfoundland, and New Brunswick are also compared with the Pebidian of Wales. The Huronian marks a period of igneous disturbance and coarse mechanical deposition succeeding to the Laurentian foldings.

Irving,[18] in 1888, after a detailed consideration of the principles applicable to the classification of the early Cambrian and pre-Cambrian formations, reaches the following general conclusions as to the use of lithological characters and structural breaks in correlation.

Lithological characters are properly used in classification:

(1) To place adjacent formations in different groups, on account of their lithological dissimilarities, when such dissimilarities are plainly the result of great alteration in the lower one of the two formations and are not contradicted by structural evidence, or if used as confirmatory evidence only, when such dissimilarities are the result of original depositional conditions.

(2) To collect in a single group adjacent formations because of lithological similarities when such similarities are used as confirmatory evidence only.

(3) To correlate groups and formations of different parts of a single geological basin when such correlations are checked by stratigraphy, and particularly by observations made at numerous points between the successions correlated.

They are improperly used:

(1) To place adjacent formations in different groups, on account of lithological dissimilarities, when such dissimilarities are merely the result of differences in original depositional conditions, and when such evidence of distinction is not confirmed by or is contradicted by structural and paleontological evidence.

(2) To collect in a single group adjacent formations because of lithological similarities when such similarities are not confirmed by or are contradicted by other evidence.

(3) To establish general correlations between the clastic groups of different geological basins, except possibly when the gneissic and true crystalline schist basement formation of one region is compared with the similar basement formation of another.

(4) To establish and determine any world-wide subdivisions of the noneruptive basement crystallines—that is, those which underlie the clastic groups here called Huronian—at least until very much more definite evidence of the existence of such subdivisions be gathered than has hitherto been done.

The structural breaks called unconformities are properly used in classification—

(1) To mark the boundaries of the rock groups of a given region.

(2) To aid in establishing correlations between the formations of different parts of a single geological basin.

(3) To aid in the establishment of correlations between the groups of regions distantly removed from one another; but caution is needed in attempting such correlations in proportion as the distances between the regions compared grow greater.

They are improperly ignored—

(1) When the evidence they offer as to separateness is allowed to be overborne by anything but the most complete and weighty of paleontological evidence.

As here used the terms system, group, and formation are the three orders of magnitude in stratigraphical subdivisions. Cenozoic, Mesozoic, and Paleozoic are systems; Carboniferous, Devonian, etc., groups; and the subordinate members of these groups are formations.

Applying these principles, it is concluded that such series as the Keweenawan and Huronian are entitled to the rank of groups (1) because, notwithstanding the fact that they include a considerable content of volcanic crystallines, they are in the main made up of genuine sedimentary strata, whose formation by the same processes which have been at work in the accumulation of later sedimentaries is easily demonstrable; (2) because they have accumulated during the existence of life on the globe, as hereafter maintained; (3) because of their great volumes, which not only are comparable with but very considerably exceed those of the ordinary rock groups; (4) because they are divisible into subordinate members which are in turn fully entitled to the rank of formations; (5) because of their entire structural separateness from the oldest of the groups above them, from each other, and from the crystalline basement rocks below them; and, finally, (6) because of their presumptively wide extent.

Conditions similar to those of the Lake Superior region recur in the Grand Canyon of the Colorado and probably also in central Texas. In Newfoundland, again, we find unconformably beneath the Cambrian, here developed to an enormous thickness, two mutually discordant series, the upper one of which is entitled on the principles advocated in this paper to full recognition as a clastic group, while the lower one is crystalline and gneissic. In numerous other regions similar conditions have been more or less distinctly made out; but the geological column, as it is now ordinarily presented, provides beneath the Cambrian for one great division only—the Archean. By some authors this Archean is recognized as divisible into Huronian and Laurentian; but very few writers, even when they have recognized the independent existence of pre-Cambrian and post-Laurentian groups, seem to have accorded to such groups the taxonomical rank to which they are entitled. Certainly there has been no general recognition of these groups, such as would lead to the provision for them of a proper place in the general geological column.

If it is agreed that all clastic formations which unconformably underlie the Cambrian are to be thrown out of the Cambrian group, it is necessary to inquire whether the new groups are to be regarded as Paleozoic. All may be regarded as Archean; Paleozoic may be carried down to the break between the Keweenawan series and the Huronian; Archean may be restricted to the gneissic basic series; and, finally, some entirely new term of equal rank with Paleozoic and Archean may be introduced to cover the formations between the gneissic series and the Cambrian. The apparent relative extent of the time intervals between these several groups and the indications presented by them of the existence of life during their deposition lead to the conclusion that there should be introduced a system term equivalent to Paleozoic and Archean. In favor of restricting Archean to the gneissic basement terrane are the facts that this is essentially a crystalline schist series, having rarely any traces of fragmental constitution, because it shows an amount of disturbance prior to the deposition of the Huronian which entirely outweighs that received by the Huronian, while the amount of denudation of the pre-Huronian land surface, as compared with that which followed the Huronian, was immensely greater; and because many believe that the exact conditions which gave rise to the pre-Huronian basement formation have never been repeated in later geological times.

There is no satisfactory evidence of the existence of life previous to the deposition of the Huronian. That it existed plentifully in the Huronian is indicated by the high development of life at the beginning of the Cambrian and its consequent necessary existence for great periods prior to that time, by the occasional discovery of obscure fossil remains, by the abundant occurrence of shales and slates filled with organic matter, and by extended ferruginous strata whose original accumulation in the form of carbonate was certainly dependent upon the existence of organic matter. That the carbon of the shales is of organic origin is shown by residual traces of hydrocarbons and by the fact that the carbonaceous substance in character and occurrence is entirely similar to that contained in the carbonaceous shales of later formations. If the term Paleozoic is to be used to cover all formations accumulated after the beginning of life, it should extend downward over the groups in question; but such is not its ordinary use, and to extend it downward over the Keweenawan and Huronian strata and the intervals indicated by the unconformities between the groups already discovered, and over such groups as shall be discovered in the vast area of the earth's surface not yet geologically known, does not seem warranted. It is therefore desirable that a new term shall be introduced of equal classificatory value, indicating that the great pre-Cambrian and post-Archean series are zoic in character and are in volume equal to or greater than the Paleozoic. For this place is suggested the term Agnotozoic, but some of our colleagues prefer the more noncommittal term Eparchean, signifying simply the position of these formations upon the Archean.

The following table shows alternative classifications suggested by the above:

System.	Group.	System.
Paleozoic	Carboniferous	Paleozoic.
	Devonian	
	Silurian	
	Cambrian	
Agnotozoic or Eparchean	Keweenawan	
	Huronian	
	(Other groups?)	
Archean	Laurentian (including Upper Laurentian)	Archean.

HUNT,[19] in 1888, summarizes the results of his work on the arrangement, subdivision, and nomenclature of the pre-Cambrian terranes as follows:

(1) Laurentian. Under this name, proposed and adopted by the author in 1854, is comprised the old gneissic terrane found especially in the Laurentide and Adirondack mountains, as well as in the great Atlantic chain and in the Rocky Mountains of the center of North America. To this same series the author has also annexed the similar gneisses of Great Britain and Scandinavia, as well as the old or central gneiss of the Alps. From the time of our first studies in Canada, in 1847, we had pointed out the existence, in this gneissic terrane, of two subdivisions, one lower, of granitoid gneiss which blends with the fundamental granite, to which succeeds with unconformable stratification a series of gneisses, also granitoid, frequently amphibolic, interspersed with quartzites and crystalline limestones, with serpentine. These two subdivisions, which we may provisionally name Lower and Upper Laurentian, have been called respectively the Ottawa gneiss and the Grenville series. In order to avoid all error it is necessary to note that the title Upper Laurentian was for some time given by Logan to the terrane designated afterward Labradorian and Norian. It is therefore through misunderstanding that some have wished to retain as a designation of the upper division of the Laurentian terrane the term Middle Laurentian.

(2) Norian. The terrane thus designated by the author in 1870 is in large part composed of those stratified rocks that have an anorthic feldspar base to which the name norite has been given. This terrane, however, includes intercalated beds of gneiss, quartzite, and crystal-

line limestone, all being rather similar to those of the Upper Laurentian terrane. These norites, which have sometimes been designated by the name gabbro, must not be confounded with the very distinct gabbros of the Huronian terrane, nor with certain plutonic rocks to which they bear mineralogical resemblances. The facies of the norites serves to distinguish them.

(3) Arvonian. This terrane is composed in large part of petrosiliceous rocks which pass into the state of quartziferous porphyry, with which, however, certain amphibolic rocks are intercalated, as well as sericitic schists, quartzites, oxides of iron, and more rarely crystalline limestone. This terrane, indicated for the first time by Hicks, in 1878, in Wales, is regarded by Charles Hitchcock as forming in North America the lower part of the Huronian terrane.

(4) Huronian. This name was given by the author in 1855 to a terrane already recognized in North America, where it rests unconformably either on Laurentian gneisses or on Arvonian hornstones. It comprises, besides quartzose, epidotic, chloritic, and calcareous schists, masses of serpentine and lherzolite, as well as euphotides, which represent in this terrane the norites of the Norian terrane, with which they are sometimes confounded under the common name of gabbro.

This terrane predominates in the Alps, where it forms the series of green stones (pietre verdi).

(5) Montalban. The studies of von Hauer, published in 1868, on the eastern Alps, and those of Gerlach on the western Alps, published the year following, agree in recognizing in these regions two gneissic terranes, that is to say, an old or central gneiss and a young or recent gneiss; the latter, which is very distinct from the old gneiss from a petrographic point of view, being accompanied by micaceous and amphibolic schists. The studies of Gastaldi, published in 1871, and those of Neri, published in 1874, while confirming Hauer and Gerlach's results, have furnished more details on these terranes and their lithological characters. It is proper to remark here that all these observers seem to be agreed in placing the horizon of the greenstones (Huronian) between the old gneiss (Laurentian) and the young gneiss.

Before he had knowledge of the first observations of these scientists, the author, in accordance with his own studies in North America, was led to identical conclusions, and in 1870 he announced the existence of a series of young gneisses quite distinct from the old gneisses and accompanied by crystalline limestones and by micaceous and amphibolic schists. To this terrane, in view of its great development in the White Mountains of New Hampshire, he gave in 1871 the name Montalban. This series, for the rest, appears identical with the young gneiss of the Alps, with gneisses and mica schists called Hercynian in Bavaria, with the granulites with dichroite rocks, mica schists, and lherzolite of the Erzgebirge in Saxony, and with similar rocks in the mountains of Scotland. This Montalban terrane in North America includes not only crystalline limestones but beds of lherzolite and serpentine, quite like the Huronian and the Laurentian. It is also in this series that are found most of the " filonian " or endogenous masses of pegmatite often inclosing emerald, tourmaline, and tin, uranium, tantalum, and niobium ores.

Gastaldi, in a memoir published in 1874, declares that the greenstones, properly so called, lie between the old porphyroid and fundamental gneiss and the recent more finely grained gneiss, more quartzose than the other, which he also designates gneissic mica schist or very micaceous gneiss passing into mica schist and often amphibolitic, the two gneissic series being, according to him, easy to distinguish. To these two divisions above the old gneiss Gastaldi added a third division still more recent. This division contains considerable thicknesses of beds designated by him argillaceous schists, or, rather, lustrous, talcose, micaceous, and sericitic (silklike) schists. Associated with these schists are found quartzites, statuary and Cipolino marbles, with dolomite, karstenite, and sometimes amphibolic rocks and surpentines, the presence of which in this division, and even in the recent gneisses, as well as in the greenstones, properly so called, seemed to him to justify the name " zone of greenstones," often given by Gastaldi to the whole of this triple group of crystalline schists which he recognized as being less old than the central gneiss.

(6). Taconian. This third division, to which Gastaldi gave no distinctive name, has, as is known, a very interesting history in Italian geology. A terrane having at the same time the same horizon and the same mineralogical characters is found greatly developed in North America, where it comprises quartzites (often schistose and sometimes flexible and elastic) and crystalline limestones, yielding statuary and Cipolino marbles. There are also found there deposits of magnetitic and of hematitic iron, as well as important beds of limonite, the latter being epigenic either from pyrites or from carbonate of iron, two species which by themselves form considerable masses. This terrane furthermore contains roofing slates, as well as lustrous and unctuous schists, ordinarily with damourite, sericite, or pyrophyllite, but inclosing sometimes chlorite, steatite, and amphibolic rocks with serpentine and ophicalcite. There are also among these schists, which are found at diverse horizons in this terrane, beds visibly feldspathic, with others of ill-defined nature, which are transformed into kaolin by aerial decomposition. These same schists also yield remarkable crystals of rutile as well as tourmaline, disthene, staurolite, garnet, and pyroxene. This terrane, which appears to be diamond bearing, was described in 1859 by Lieber under the name Itacolumitic group. Eaton, as far back as 1832, had placed the quartzites and limestones forming the lower members of the group in the Primitive terrane, while the argillites, found toward the summit of the same group, were regarded as constituting the lower division of the Transition terrane, covered, according to him, unconformably by the fossiliferous graywacke (first graywacke) which formed the upper division of the same Transition terrane. Emmons, on his part, in 1842, comprised in what he called the Taconic system all this crystalline series, as well as the graywacke; but in 1844 he separated the latter, in which he had recognized the existence of a trilobitic fauna, giving it the name Upper Taconic. Long studies have convinced the senior author that this upper division is entirely independent of the Lower Taconic, with which this fossiliferous graywacke is in contact only in relatively restricted regions, while in other localities it rests directly on older crystalline terranes. Seeing, moreover, that the Lower Taconic is found alone in a great number of localities from the Gulf of St. Lawrence to Alabama on the south and to Lake Superior on the west, and recognizing also the fact that the Upper Taconic really forms part of the Cambrian terrane (as was recognized by Emmons in 1860), the author proposed as far back as 1878 to restrict the employment of the term Taconic to this crystalline and infra-Cambrian series which forms the Lower Taconic of Emmons and the Itacolumitic group of Lieber, and to give it the name Taconian terrane.

The mineralogical resemblances existing among the various crystalline terranes mentioned above are easy to recognize. The type of rocks with orthose base that appears in the fundamental granite and the Laurentian gneisses is also found in the quartziferous porphyries of the Arvonian and the gneiss of the Montalban, and less distinctly in the feldspathic rocks of the Taconian. The nonmagnesian micas, rare in the fundamental granite and the Laurentian gneisses, are found abundantly represented in the gneisses and mica schists of the Montalban, as well as in the lustrous schists found in the Huronian and Taconian terranes, and even predominate in the latter. It is still to be remarked that the simple silicates of alumina, such as andalusite, disthene, fibrolite, and pyrophyllite, which seem foreign to the oldest terranes, abound in the Montalban and also appear in the Taconian. At the same time the crystalline limestones, the oxides of iron, and the calcareous and magnesian silicates are found represented in each terrane beginning from the fundamental granite. The chemical and mineralogical differences between these various terranes are greater than the resemblances, which has not prevented certain observers from confounding the recent gneiss with the old gneiss. In fact, the resemblances between the Huronian and Taconian terranes have led the late Professor Kerr, in North Carolina, to refer the latter terrane to the Huronian. In the vicinity of Lakes Superior and Huron, too, where the Laurentian, Norian, Arvonian, Montalban, and Taconian terranes are all found, the outcrops of the Taconian have been confounded with those of the Huronian terrane by Murray and other observers. In 1873, however, the author, distinguishing between the two, gave to the Taconian terrane in this region the provisional name Animikie series. Not until later did he recognize the fact that this series, which in certain localities rests unconformably on the Huronian terrane, is the Taconian. Emmons, on the contrary, who knew the existence in this region of what he called the Lower Taconic, thought that the terrane to which in 1855 the author had given the name Huronian was identical with this same Lower Taconic or Taconian. The differences between the two terranes in the basin of Lake Superior, indicated first by Logan and afterward by the author, appear very clearly from the recent studies of Rominger. On the various crystalline terranes, including the Taconian, there rests in this region unconformably an enormous series of sandstones and conglomerates, with contemporary plutonic rocks, the whole being remarkable for its content of metallic copper. This series, which had been alternately confounded with the Huronian and Taconian terranes on the one hand and with the trilobitic sandstones of the Cambrian on the other, was for the first time separated by the author in 1873 under the name Keweenaw group, a term which he in 1876 converted into Keweenian terrane. It still remains to be determined whether this series, on which these same trilobitic sandstones rest unconformably, should form part of the Cambrian terrane or whether it should form a distinct terrane between the Taconian and the Cambrian.

Dawson,[20] in 1889, presents a brief note on Cryptozoon and Archeozoon found in the pre-Cambrian. A general discussion is given of the biological affinities of the Cryptozoon and Archeozoon, and descriptions are quoted of younger forms which may be the successors of the pre-Cambrian forms.

Bell,[21] in 1889, characterizes the Huronian as the great metalliferous series of Canada. While rocks of igneous origin constitute a marked feature in the Huronian system, a large proportion of it is made up of rocks of an undoubted sedimentary character. On the other hand, it is questionable if the great bulk of the Laurentian rocks can be proved to have been deposited from water. It is supposed by many that the foliation of much of the gneiss may have been produced by pressure and some kind of flowing movement in an igneous mass. Whatever view we may take of the origin of the common Laurentian gneiss, which forms the surface of the country over so vast an extent of the Canadian half of North America, the commencement of the Huronian period marks a great change which then came over the earth—a change characterized by widespread volcanic outbursts and by evidence of the existence of water (perhaps the first) on the surface of the globe, and of certain progress in the building up of the aqueous deposits which has been going on ever since.

Bell,[22] in 1890, gives a general account of the Archean. The Azoic or Archean period is divided into the Laurentian and Huronian systems, into which the primitive rocks of all countries may be classified, and which everywhere are essentially the same and retain the same relative positions. In some instances newer rocks have been so altered locally or over considerable tracts as to resemble the Azoic, but there is generally found some means of distinguishing between them. In Canada and the United States the Laurentian and Huronian are usually intimately associated, but their lithological features and internal characters are sufficiently distinct to separate them. The Huronian rocks are less contorted or corrugated on the small scale than the Laurentian, but on the large scale they partake of the same foldings which have affected the latter. The Huronian rocks seem to be interwoven with the Laurentian as basins or troughs more or less elongated, and as tracts of angular and other forms filling spaces between great nuclei or rounded areas of Laurentian rocks.

The Laurentian system is divided into two formations, the lower of which is sometimes called the Primitive Gneiss series. It consists essentially of obscurely foliated or stratiform granitic or syenitic gneiss. The prevailing colors of the Lower Laurentian gneiss are grayish and reddish. In some districts the Laurentian rocks are cut by dikes of greenstone or trap. In the Upper Laurentian are placed both the anorthosite rocks and the limestone-bearing series of eastern Ontario. The anorthosites, which are considered by some as eruptives and by others as bedded rocks interlaminated with the limestones, may be in part of both origins. Anorthosites, after spreading out upon the surface of the earth or the bottom of the sea, may have become incorporated in a conformable manner with the contemporaneous deposits, while others may have flowed over preexisting rocks which were not disturbed. Between the Upper and Lower Laurentian there may be a general want of conformity. The Upper Laurentian contains metallic ores and very numerous minerals, which are not found in the Lower Laurentian. The gneisses of the Upper and Lower Laurentian often have a close resemblance. As the evidence is so strongly in favor of the aqueous origin of a part of the Upper Laurentian at least, this lends support to the view that even the primitive gneisses may have been formed by the action of water during some early condition of the earth, of which we can form but little conception, judging by the later stages of its history. Eozoon is regarded as a myth, and the limestones, iron ores, graphite, and apatite are not considered as evidence of the existence of animals or plants in Laurentian times. The limestones may be chemical sediments; the graphite and apatite occur principally as vein matter;

the iron ores occur in greater masses than in deposits of organic origin, and their mode of occurrence is opposed to any theory of this kind. The Upper Laurentian rocks seem to be much more limited in geographical extent than the Lower Laurentian.

The Huronian system in Canada has a great thickness and variety of strata, for the most part crystalline, but in less degree than the Laurentian, together with many unstratified igneous masses. Like the Laurentian it is azoic, or devoid of any trace of organic life, so that the distinction between the two systems is based entirely on lithological grounds. The difference in this respect is great, and is easily recognized by those who have paid any attention to geology. The prevailing dark-green and dark-gray colors of the Huronian offer a marked contrast to the lighter grays and reddish grays of the Laurentian. The latter are massive and coarsely crystalline, while the former are usually fine grained and schistose or fissile, this cleavage structure constituting a striking difference from the solid Laurentian. There are some exceptions to this rule, such as the light-colored quartzites and the granites and syenites of the Huronian, to be noticed further on. The change in passing from one to the other is often sudden and complete, but sometimes beds of passage are met with. The Huronian is the great metalliferous system of Canada. Although the Huronian strata have generally been thrown into sharp folds, or stand at high angles, they are, as a rule, less bent about or contorted than the Laurentian. The total volume of the system is very great, probably not far from 40,000 or 50,000 feet, or perhaps even more.

In Canada, as far as our investigations have gone, the two systems appear to be everywhere conformable to each other, but in rocks of so ancient date which have undergone so profound structural changes, owing to pressure, etc., affecting alike the stratified and unstratified portions, this appearance may not everywhere indicate a truly conformable sequence. Both sets of rocks having been thrown by lateral pressure into sharp folds, standing at high angles to the horizon, the Huronian often appears to dip under the older Laurentian, but this is merely the effect of overturning, and does not show that a part of the Laurentian is newer than the locally underlying Huronian. Notwithstanding the geographical relations of the two sets of rocks, their general difference in character and composition would indicate that some great change in terrestrial conditions had occurred when the formation of the one system ended and that of the other began. In the Laurentian an "acid" or siliceous composition prevails, whereas the Huronian rocks as a whole are more basic, chemically speaking. The latter can be shown to be very largely of volcanic origin, although this may not always be obvious at first sight.

The term Huronian is made to include all the rocks lying between the Laurentian below it and the Cambrian or earliest fossiliferous rocks above. Among the areas placed with the Huronian are the Keewatin and similar rocks. In the Huronian are numerous areas of northern Canada, and perhaps certain of the rocks of Hastings and Lanark counties, some of the crystalline rocks of the Eastern Townships and the provinces of New Brunswick, Nova Scotia, Cape Breton, and Newfoundland. In the Cambrian system are placed in ascending order the Animikie, Nipigon, and Potsdam formations. Between the Huronian and the Cambrian is a great unconformity. Between the Animikie and the Nipigon and between the Nipigon and the Potsdam are probable unconformities.

WALCOTT,[23] in 1890, gives a full account of the Lower Cambrian or *Olenellus* zone.

The base of the *Olenellus* zone is considered to be where the genus *Olenellus*, or the fauna usually accompanying it, first appears; beneath that horizon the strata are referred to some of the pre-Cambrian groups of rocks. In some cases the underlying rocks are in layers, conformably beneath the Cambrian, and no physical separation of the two groups is possible. In other instances the subjacent rocks are the remains of the old Archean continent, near the shores of which much of the life of this portion of the Cambrian period existed.

The line of demarcation between the Cambrian and the pre-Cambrian may be considered (1) at the base of the *Olenellus* zone, in continuous sections; (2) at the line of an unconformable contact between any member of the Cambrian group and the subjacent Algonkian or Archean; (3) at the line of unconformable contact which is the base of the *Olenellus* zone.

Placed in the Algonkian under this definition are 11,000 feet of quartzites conformably below the *Olenellus* in the Wasatch; 10,000 feet of argillites, sandstones, quartzites, and conglomerates conformably beneath the *Olenellus* in British Columbia; 12,000 feet of sandstones, shales, and limestones unconformably beneath the lowest known Cambrian in the Grand Canyon of Colorado; a similar series of rocks unconformably beneath the Cambrian in Llano County, Tex.; a series unconformably below the Upper Cambrian in the Adirondacks; and the rocks of St. Marys and Placentia Bay, Newfoundland, which are unconformably below Lower Cambrian strata. In the Grand Canyon, in a bed of dark argillaceous shale 3,550 feet from the summit of the section, was found a small patelloid or discinoid shell and a fragment of what appears to be the pleural lobe of a segment of a trilobite, also an obscure, small *Hyolithes* in a layer of bituminous limestone. In layers of limestone lower in the section an obscure stromatoporoid form occurs in abundance. These fossils indicate a fauna, but do not tell what it is.

The *Olenellus* fauna includes Spongiæ, Hydrozoa, Actinozoa, Echinodermata, Annelida, Brachiopoda, Lamellibranchiata, Gasteropoda, Pteropoda, Crustacea, and Trilobita. The abundance of the *Olenellus* fauna shows that the life in the pre-*Olenellus* seas was large and varied. The few traces of it known prove little of its character, but they show that life existed in a period far preceding Lower Cambrian time, and they foster the hope that abundant remains will yet be discovered.

DANA,[24] in 1892, gives the following as the philosophical divisions of pre-Cambrian times, although the early physical and biological conditions of the globe are not within the range of observation:

I. The Astral eon, as it has been called, or that of liquidity.

II. The Azoic eon, or that without life.

1. The lithic era, commencing with completed consolidation; the time when lateral pressure for crust disturbance and mountain making was initiated, and when metamorphic work began.
2. The oceanic era, commencing with the ocean in its place; oceanic waves and currents and embryo rivers beginning their work about emerged and emerging lands, and the tides the retarding of the earth's rotation.

III. The Archeozoic eon, or that of the first life.

1. The era of the first plants; the algæ and later the aquatic fungi (bacteria); commencing possibly with the mean surface temperature of the ocean about 180° F.
2. The era of the first animal life; the protozoans, and forms related to the embryos of higher invertebrate species, commencing possibly with the mean surface temperature of the waters about 120° F., and ending with 90° F. or below.

While these divisions mark off great steps in the progress of the developing earth, the rocks bear no marks of them that can be distinguished.

The Huronian period covered probably much of Archeozoic time, and this is all that can be said in the way of correlation. It is well to note here that if the Eozoon is really animal in origin the "Laurentian" rocks of Canada in which it occurs must be Huronian or the later of Archean terranes.

VAN HISE,[25] in 1892, summarizes knowledge to date on the pre-Cambrian areas of North America and discusses the nature and correlation of the pre-Cambrian series. This is the first attempt to make a concise statement of this complex subject. The present bulletin is a restatement of the subject in the light of the studies which have been made since 1892.

WILLIAMS,[26] in 1894, discusses the distribution of the ancient volcanic rocks along the eastern border of North America, from Newfoundland into Georgia, and shows their distribution on a sketch map. The areas of these ancient volcanic rocks now known fall roughly in two parallel belts; the eastern belt embraces the exposures of Newfoundland, Cape Breton, Nova Scotia, the Bay of Fundy, coast of Maine, Boston basin, and the central Carolinas; the western belt crosses the Eastern Townships and follows the Blue Ridge through southern Pennsylvania, Maryland, Virginia, and North Carolina to Georgia. This is largely a summary from the work of other writers, supplemented by field observations in the Piedmont area. For the most part age is not discussed, although the pre-Cambrian age of the South Mountain volcanic rocks is mentioned.

BROOKS (W. K.),[27] in 1894, discusses the origin of the oldest fossils and explains the lack of fossils in the pre-Cambrian and their sudden appearance in the Cambrian, as follows:

1. The primitive fauna of the sea bottom was entirely animal, without plants, and it at first depended directly upon the pelagic food supply.

2. It was established around elevated areas in water deep enough to be beyond the influence of the shore.

3. The great groups of animals were rapidly established from pelagic ancestors.

4. The animals of the bottom rapidly increased in size and hard parts were quickly acquired.

5. The bottom fauna soon produced progressive development among pelagic animals.

6. After the establishment of the fauna of the bottom, elaboration and differentiation among the representatives of each primitive type soon set in and led to the extinction of connecting forms.

Thus is explained the high degree of differentiation and development shown by the early Cambrian fauna.

VAN HISE,[28] in 1896, discusses principles of North American pre-Cambrian geology. The first half of the volume treats of the principles of structural geology particularly applicable to pre-Cambrian study. On a structural basis the earth's lithosphere is assumed to be made up of a zone of fracture at the surface, grading below into a zone of rock flowage, and attempts are made on several hypotheses to determine the depth below the surface to which rock flowage must begin because of the conditions of pressure there, and it is concluded that this depth is seldom greater than 10,000 meters. The structural phenomena of the zone of rock flowage are discussed under the heads of folding and cleavage, and those of the zone of rock fracture under the heads of joints, faults, fissility, etc. Other subjects discussed are methods of field observation in closely folded districts, criteria for determining unconformities, and some of the elementary principles of the metamorphism of rocks.

Part II is a résumé of knowledge to date on pre-Cambrian regions of North America, with a general discussion of the nature and correlation of the pre-Cambrian series. As the present bulletin is essentially a revision and amplification of this résumé, this part of Van Hise's principles will not be here summarized.

Ells,[29] in 1897, gives a general account of the Archean of eastern Canada, including a review of the various classifications made by the earlier geologists, and their recent modifications. It is concluded that it is possible to reduce the great series of the so-called Laurentian rocks to two principal divisions, viz, a lower Basal or Fundamental gneiss, in which all traces of sedimentation are wanting, and which may be regarded as representing in altered form some portion of the original crust of the earth; and a newer, secondary series, derived doubtless from the decay of the former, in which the evidences of clastic origin are manifest. On this basis the arrangement of the systems for eastern Canada would be as follows:

Laurentian, nonsedimentary:

- Basal or Fundamental gneiss (Ottawa gneiss), representing in altered form the original crust of the earth, and the lowest known series of rocks; without evidence of sedimentary origin.

Huronian, partly sedimentary and partly igneous:

- Grenville and Hastings series, comprising limestones, quartzites, gneisses, etc., of Ontario and Quebec, in the Ottawa district.
- Schists and altered slates, chloritic and other crystalline rocks of the Eastern Townships of Quebec and the Gaspe Peninsula.
- Felsitic and gneissic rocks of northern New Brunswick.
- Gneiss, quartzite, and limestone, of the so-called Laurentian of southern New Brunswick, regarded as the equivalents of the Grenville and Hastings series, felsites and schistose rocks of the Coldbrook, Kingston, and Coastal divisions, the apparent equivalents of the rocks of the Sutton Mountain anticlinal.
- Felsitic and syenite rocks of eastern Nova Scotia and northern Cape Breton, with their associated crystalline limestones and serpentines.

Cambrian:

- Cambrian slates, sandstones, and conglomerates.

Dawson,[30] in 1897, gives a general account of the pre-Cambrian rocks of Canada. This is largely a discussion of pre-Cambrian classification and nomenclature, based on a review of early and recent work on the pre-Cambrian of Canada, and will, therefore, not be fully summarized. A few of the more important conclusions may, however, be mentioned.

The Laurentian still includes both Fundamental gneiss and the Grenville series.

The Huronian proper, under whatever local name it may be classed, still remains a readily separable series of rocks.

The Upper Laurentian, Labradorian, Norian, or anorthosite group is found to consist essentially of intrusive rocks, later in age than the Grenville, but in all probability pre-Paleozoic.

The general tendency in our advance in knowledge appears to be in the direction of extending the range of the Paleozoic downward, whether under the old name of Cambrian or under some other name applied to a new system defined or likely to be defined by a characteristic fauna; and under Cambrian or such new system, if it be admitted, it is altogether probable that the Animikie and Keweenawan rocks must eventually be included.

The introduction of the term Algonkian, proposed to include the recognizable sedimentary formations below the *Olenellus* zone and their igneous equivalents, is believed to be a backward step, for the following reasons: It detaches from the Paleozoic great masses of conformable and fossiliferous strata beneath an arbitrary plane and unites these under a common systematic name with other vast series of rocks, now generally in a crystalline condition; it includes as a mere interlude what, in the region of the Protaxis, is one of the greatest gaps known to geological history; and it does not in the least degree remove the difficulty found in defining the base of the Grenville series.

DAWSON,[31] in 1897, in an account of the physical geography and geology of Canada, sketches the distribution and characters of the pre-Cambrian rocks. This is largely a general summary of the present state of knowledge concerning the geology of Canada, and will therefore not be fully reviewed.

WALCOTT,[32] in 1899, discusses pre-Cambrian fossiliferous formations of North America.' In two cases only have fossils of undoubted organic origin been shown to occur in formations of reasonably certain pre-Cambrian age, namely, the Grand Canyon of Arizona, and the Belt terrane of Montana. The Etcheminian terrane of New Brunswick and Newfoundland is doubtfully a third instance.

A brief account is given of the stratigraphy of each of the areas of pre-Cambrian sedimentary rocks. No new points appear except in the description of the Belt terrane of Montana; the account of the Belt terrane is therefore the only one summarized with reference to stratigraphy.

The Belt terrane of Montana covers an area of more than 6,000 square miles in central Montana. The principal beds of the terrane are as follows:

	Feet.
Marsh shales	300
Helena limestone	2,400
Empire shales	600
Spokane shales	1,500
Greyson shales	3,000
Newland limestone	2,000
Chamberlin shales	1,500
Neihart quartzite and sandstone	700
	12,000

Throughout the area the Belt terrane is overlain unconformably by middle Cambrian rocks (Flathead). The Cambrian rocks rest on various members of the Belt series, and in places the Belt terrane is entirely wanting, the Cambrian resting directly on the Archean schists. In such cases, moreover, the character of the Belt beds indicates that the Cambrian overlaps the Belt series. The base of the Cambrian is not markedly conglomeratic. At most of the outcrops where the lower beds of the Flathead (Cambrian) sandstone come in contact with the Belt rocks the dip and strike of the two are usually conformable, so far as can be determined by measurement. This holds good all around the great Belt Mountain uplift. It is only when contacts are examined in detail, as near Helena, that the minor unconformities are discovered, and only when comparisons are made between sections at some distance from one another that the extent of the unconformity becomes apparent. In general from 3,000 to 4,000 feet of the upper strata of the Belt terrane were removed by erosion in late Algonkian time before the middle Cambrian was deposited. It is believed that an unconformity of this extent is sufficient to explain the absence of lower Cambrian rocks and fossils and to warrant the placing of the Belt terrane in the Algonkian system.

The fossils thus far found in the Belt terrane occur in the Greyson shales at a horizon approximately 7,700 feet beneath the summit of the Belt terrane at its maximum development. The fauna includes four species of annelid trails and a variety that appears to have been made by a minute mollusk or crustacean. There also occur in the same shales thousands of fragments of one or more genera of crustaceans.

The fossils of the Grand Canyon upper Cambrian series consist of specimens of a small discinoid shell found in the upper division of the Chuar terrane, and a Stromatopora-like form from the upper portion of the lower division and the central portion of the upper division of the Chuar. Other obscure forms appear whose identification is doubtful.

In New Brunswick certain rocks below the middle Cambrian, according to Matthew, contain fossils which may be pre-Cambrian.

The Llano series of Texas is a series of alternating sandy shales, sandstone, and limestone, very similar to those of the Grand Canyon pre-Cambrian series and overlain by a middle Cambrian sandstone similar to the Tonto sandstone of the Grand Canyon district. No fossils have been found in these rocks, although no systematic search for them has been made.

The Avalon series of Newfoundland includes all the pre-Cambrian sedimentary rocks of that area. Overlying them are Cambrian strata carrying *Olenellus* fauna.

The *Aspidella* of the Momable slates is probably of organic origin, but it may be questioned. Other reported forms are inaccessible for study.

In the Lake Superior country markings have been reported as found in the Huronian iron formation of the Menominee iron district of Michigan. An examination of the specimens indicates that they probably are from the basal detrital material of the Cambrian which rests upon the Huronian iron formation. In the Animikie rocks of the Lake Superior region the evidence of life consists of the presence of graphitic material in the slates and of a supposed fossil mentioned by G. F. Matthew. In the Minnesota quartzite of the upper Huronian series lingula-like forms and an obscure trilobitic-looking impression are described by Winchell. The latter has been examined and the conclusion is reached that it is of inorganic origin. As to the lingula forms, the weight of evidence is in favor of their being small flattened concretions.

In general, the reported discoveries of fossils in the crystalline rocks of the Algonkian are as yet too problematic to be of value to the geologist and paleontologist. Apparently the best that can be said of Eozoon and allied forms is that they may be of organic origin, but it is not yet proved. The same appears to be true of the supposed fossil sponges described by G. F. Matthew from the Laurentian rocks of New Brunswick. The graphite in pre-Cambrian forms is probably in many cases of organic origin, but of the character of the life we know nothing.

Palæotrochis, formerly referred to as a pre-Paleozoic coral, is determined by J. A. Holmes and J. S. Diller as of inorganic origin.

Ells,[33] in 1899, gives a historical account of the geological nomenclature of that part of Canada which extends roughly from the Red River of Manitoba eastward over Canada. The present usage with reference to pre-Cambrian rocks may only be mentioned.

In Nova Scotia the term pre-Cambrian has been given to certain old crystalline rocks which were found to underlie the recognized Cambrian of the coast or of the gold series, and which were found to strongly resemble certain portions of the Laurentian or Huronian of the western provinces.

In New Brunswick there has been little change in the nomenclature proposed by Matthew, Bailey, and Hunt. The lowest division of the crystalline rocks was held to conform most closely in its details to the Laurentian of the Canadian Survey. This series was divided into a lower and an upper division, the former of which was regarded as the equivalent of the lower or Fundamental gneiss of the Ottawa district, while the latter was supposed to represent the limestone and gneiss of the Grenville series of Quebec. The Huronian was made to include three divisions, viz, the Colebrook, the Kingston, and the Coastal.

Since this time Matthew has introduced the term Etcheminian to designate certain fossiliferous sediments found beneath the middle Cambrian, probably belonging to the more recent portion of the pre-Cambrian formations.

In Ontario and Quebec the oldest granite gneiss may be styled Laurentian. The second member of the scale, or the Huronian, may be made to include, as its lowest portion, that part of the crystalline series, once regarded also as part of the Laurentian system, which is known locally under the names Grenville and Hastings series, the relations of which to the Laurentian proper are apparently of two kinds—a stratigraphic sequence, with a probable unconformity, owing to difference in origin, and a contact of intrusion. Portions of the Grenville and Hastings series correspond, while the latter is carried upward through less altered sediments to the upper members of the Huronian system.

In the Lake Superior region the Huronian is succeeded upward by the rocks of the Cambrian, represented by the Upper Copper-bearing series, or the Animikie and Nipigon groups; while in eastern Ontario this portion of the scale is apparently entirely lacking, the formation succeeding the crystalline series being the Potsdam sandstone, which is now held to represent the lowest member of the Cambro-Silurian or Ordovician system.

Ami,[34] in 1900, summarizes the geology of Canada and indicates the meaning and correlation of the principal terms employed in Canadian geological nomenclature.

Ami,[35] in 1900, briefly summarizes the salient features of the geology of the principal cities of eastern Canada, including St. John, Ottawa, Quebec, Montreal, and Toronto.

Coleman,[36] in 1902, discusses the classification of the Archean (pre-Cambrian of the United States Geological Survey) and proposes the following:

<table>
<tr><td rowspan="3">Middle and lower Cambrian (?) or Algonkian (?)</td><td>Keweenawan.</td></tr>
<tr><td>Unconformity.</td></tr>
<tr><td>Animikie.</td></tr>
</table>

Eparchean interval.

<table>
<tr><td rowspan="5">Archean</td><td colspan="3">Laurentian=Fundamental gneiss, etc.</td><td></td></tr>
<tr><td colspan="3">Eruptive unconformity.</td><td></td></tr>
<tr><td rowspan="3">Huronian</td><td colspan="2">Upper Huronian or Huronian proper.</td><td rowspan="3">=Grenville and Hastings series.</td></tr>
<tr><td colspan="2">Unconformity.</td></tr>
<tr><td>Lower Huronian or Keewatin.</td><td>Schistose pyroclastics and eruptives.
Coutchiching.</td></tr>
</table>

Wilson,[37] in 1903, describes the Laurentian peneplain of the great pre-Cambrian shield of Canada and adjacent portions of the United

States. The peneplain is an ancient one, which has undergone differential elevation, has been denuded, and subsequently slightly incised around the uplifted margin. At several places on the margin, as exposed to-day, the dissection may be regarded as submature. The date of the major development of the peneplain is not determined, but may be pre-Ordovician or Cretaceous. Around the southern margin between Montreal and Winnipeg there are traces of a peneplain (or probably more than one) of still earlier date, upon which Paleozoic sediments were laid down, and which has been uncovered by processes of degradation and denudation since the differential uplift of the latest peneplain.

Van Hise,[38] in 1904, discusses principles of metamorphism applicable to the study of pre-Cambrian and other metamorphic rocks and cites many illustrative pre-Cambrian rocks and localities.

Willmott,[39] in 1904, finds a steplike regularity in the contact of the Archean (pre-Cambrian of the United States Geological Survey) and post-Archean rocks in the region of the Great Lakes and believes it to be explained by a dislocation in the Archean before the deposition of the post-Archean sediments.

Darton,[40] in 1905, in connection with a discussion of the artesian wells of the central Great Plains, publishes a map giving the best available information of the distribution of the pre-Cambrian rocks of southwestern Minnesota, South Dakota, Wyoming, and the eastern part of Colorado, and briefly discusses their distribution and structural relations.

Willis,[41] in 1906, in cooperation with the Canadian, Mexican, and United States geological surveys, publishes a geological map of North America with explanatory text. This is by far the best representation of the distribution of the pre-Cambrian rocks as a whole that has been published to this date. The pre-Cambrian rocks are mapped in part as unclassified, in part as Eo-Algonkian, including the Lower Huronian and Keewatin of the Lake Superior country and the Grenville series of eastern Canada, and, third, the Neo-Algonkian, including the Belt terrane of Montana, the quartzites of the Colorado River, and the Keweenawan and Animikie of the Lake Superior region and northern Canada. The gold-bearing slates of Nova Scotia, the Ocoee series of the Piedmont area, and the Adams Lake and Nisconlith series of British Columbia are all mapped as Cambrian, while the Belt terrane, with which they are unrelated in the present paper, is mapped as Algonkian. The Animikie series of the Lake Superior region has erroneously been mapped with the Eo-Algonkian rather than with the Neo-Algonkian. The Keewatin and Lower Huronian are mapped under one color because of the impossibility in the present state of knowledge of separating them over much of Canada. The use of the term Algonkian for this combination is, however, unacceptable to the Canadian geologists, who do not regard the term as necessary, as well as to the American geologists, who regard the Keewatin as Archean, unconformably below the Algonkian.

DALY,[42] in 1907, concludes that the lime salts of the pre-Cambrian ocean, inherited from Azoic time, were precipitated as calcium carbonate comparatively soon after the introduction of animal life into the sea.

During most of Eozoic time—that is, pre-Cambrian time in which animal life existed—the ocean was practically limeless; calcareous secretions by animals were impossible.

Tests and skeletons of pure chitin were possible in Eozoic time, but were not abundantly preserved until some carbonate or phosphate of lime was built into those structures. The calcareo-chitinous tests of Cambrian and Ordovician trilobites and shells of brachiopods represent a transition stage between the Eozoic eon of dominantly soft-bodied animals and the post-Cambrian eon of dominantly lime-secreting animals. The notable fossilization of brachiopods, trilobites, mollusks, etc., was impossible until near the beginning of Cambrian time. Indeed, the conditions for truly abundant fossilization of calcareous forms were not established until after the Cambrian period. The striking variety or entire lack of organic remains in the thick Cambrian sediments of British Columbia, Alberta, Idaho, and Montana, and in many other parts of the world, may be thus explained.

Eozoic limestones, dolomites, magnesian limestones, and calcareous and magnesian deposits generally were chemically deposited through the medium of organic ammonium carbonate. This alkali acted on the primeval calcium and magnesium salts of the ocean and on the calcium and magnesium salts introduced to the ocean by pre-Cambrian rivers. A similar origin is suggested for the iron carbonate occurring in Eozoic sedimentary beds. It is also suggested that possibly the silica of the cherts and jaspers characteristically associated with these carbonates was likewise thrown out of solution by ammonium carbonate of organic origin. The petroleum and natural gas emanations from Eozoic sedimentary rocks receive explanation if the fundamental postulate of abundant Eozoic marine life be accepted.

COLEMAN,[43] in 1907, argues for a Lower Huronian ice age on the evidence of the nature of the graywacke and conglomerate in the Lower Huronian rocks of the Cobalt district and adjacent territory.

VAN HISE,[44] in 1908, outlines the development of knowledge of the dual division of the pre-Cambrian, emphasizes the fact that this is based on physical differences rather than on differences in life evidences, and concludes that no subdivision is possible on the "zoic" basis and that therefore terms such as Archean and Algonkian are desirable to indicate the physical classification.

Daly,[45] in 1908, from a consideration of the origin of augite andesite and of related ultra-basic rocks, suggests that basaltic magma forms the universal substratum of the earth's crust to-day and has formed that substratum since Keewatin time; that this basaltic substratum is stratified by density so that the lower layer of the crust is crystallized basaltic magma and the upper layer is dominantly acidic. The fundamental gneiss of the pre-Cambrian was crystallized in pre-Keewatin time and through it the basic Keewatin lavas were erupted. By the spontaneous differentiation of the primary basalt through fractional crystallization, the few rock types specially discussed in this paper have been locally derived. Most of the other eruptive rocks are, on this same working hypothesis, regarded as derived from the formation and differentiation of magmas which are the product of the solution of the acidic original gneissic shell and of its sedimentary veneer in the primary basalt.

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CHAPTER III.

LAKE SUPERIOR REGION.

SECTION 1. MICHIGAN.

SUMMARY OF LITERATURE.

HOUGHTON,[1] [a] in 1840, divides the rocks in the south and southeastern part of the Upper Peninsula into Primary and sedimentary. The Primary region stretches continuously in a northwestward direction for many hundreds of miles, skirting portions of the shores of Lake Superior, and constituting the highlands between that lake and the Lake of the Woods. From these highlands it stretches a little east of Lake Winnipeg far to the northwest, finally constituting the immense "barren grounds" of the British Possessions. The rocks of St. Marys River and adjacent region comprise greenstone, argillite, and granular quartz rock, which passes into an almost conglomeratic quartz rock. In this occur small quantities of hematitic iron ore. The sedimentary rocks include the Lake Superior sandstone and lime rock and shales. The Lake Superior sandstone is nearly continuous on the southern shore of Lake Superior, and in its easterly prolongation rests against and upon the Primary range of St. Marys River, where it passes conformably below the limestone above. The Lake Superior sandstone, in its easterly prolongation, does not attain a very great thickness, but in proceeding westerly this thickness is vastly increased, attaining on the south shore of Lake Superior to several hundred feet. A careful search for fossils in this sandstone has failed to reveal a single one.

HOUGHTON,[2] in 1841, divides the older rocks of the Upper Peninsula of Michigan into (1) Primary, (2) trap, (3) metamorphic, (4) conglomerate, (5) mixed conglomerate and sandstone, (6) lower or red sandstones and shales, and (7) upper or gray sandstone. The Primary rocks are in a broad sense granite. The granitic rocks are largely traversed by greenstone dikes. The trap rocks of the district in a chronological order would follow the metamorphic slates and quartz rocks, but the granitic rocks pass by almost insensible gradation into the greenstones of the trap formation.

The sedimentary rocks on the south and southeast of the main trap range are scarcely disturbed, while those on the north and northwest-

[a] For notes see end of chapter, p. 386.

erly sides are invariably tilted to a high angle near the range of hills. The sedimentary rocks on the north are traversed by numerous dikes, varying in thickness from 50 to 400 or 500 feet. The trap rocks on this northwestern escarpment were in an intense state of ignition while in contact with the sedimentary rocks, as shown by the great changes which the sedimentary rocks have undergone. The author is disposed to regard the amygdaloid as due to the fusion of the lower portions of the sedimentary rocks.

At Presque Isle is a little isolated knob of trap which has been uplifted, as is shown by the way in which the stratification of the adjacent sedimentary rocks has been disturbed. They invariably dip at a high angle in all directions from the trap. At the immediate line of junction the character of both rocks is lost, and the sedimentary rocks for a distance of several hundred feet have been shattered while retaining their original position, and were again cemented by an injection of calcareous matter.

The area of country occupied by the metamorphic group is less than by the Primary or trap. The group is made up of an alternating series of talcose and mica slates, graduating into clay slates, with quartz and serpentine rocks, the quartz rocks being by far the most abundant. The metamorphic rocks are occasionally traversed by trap dikes.

The conglomerate rock, the lowest of the sedimentary rocks, is invariably connected with or rests upon the trap rock. It is very variable in thickness and is without doubt a trap tuff which has accumulated or been deposited around the conical knobs of traps during their gradual elevation. The pebbles of the rock consist of rounded masses of greenstone and amygdaloid. They are usually firmly cemented by calcareous and argillaceous material. Resting conformably upon the conglomerate is a mixed conglomerate and sand rock. This mixed rock occurs upon Isle Royal and was seen to be very widespread on the south shore. The conglomeratic part of the mixed rock has the same character as the conglomerate rock. Dikes of greenstone are found in this mixed rock, but less frequently than in the rock below. The red sandstone is the chief rock that appears upon the immediate coast of the south shore of Lake Superior. The Primary, metamorphic, and trap rocks are almost invariably surrounded or flanked at their bases by this sand rock. The material of this sand rock differs widely from the conglomerate rocks, for these are made up of materials clearly of trappean origin and very rarely of quartz, while the red sandstone is composed of materials derived from the granitic and metamorphic rocks, in which quartz occurs abundantly. The red sand rock is less frequently traversed by dikes than the rocks before described, although they are sometimes noticed traversing the whole of the several rock formations, including the red sandstone. The upper or gray sand rock conforms to the limestone above it, and rests conformably upon the uptilted edges of the sand rock below.

LOCKE,[3] in 1844, describes the rocks of Copper Harbor as well as the whole of Keweenaw Peninsula as decidedly metamorphic, showing every degree of change produced by igneous action, from unchanged sandstone to compact greenstone. The original stratification is generally more or less evident; some layers bear evidence of semi-fusion with a corresponding degree of induration, while others seem scarcely to have been altered.

ROGERS,[4] in 1846, describes the red sandstones and conglomerates of Lake Superior as resting unconformably upon highly inclined slate rocks undoubtedly Primal and upon the Potsdam sandstone of the New York Survey at Chocolate and Carp rivers, and therefore regards them as of post-Paleozoic age.

LOCKE,[5] in 1847, speaks of the relation of the trap rock and sandstone at Presque Isle, and submits a drawing of it.

WHITNEY,[6] in 1847, describes the wide band of trappean rocks commencing at the extremity of Keweenaw Point as continuing its course uninterruptedly as far as Montreal River. Its distance from the lake between Portage and Ontonagon is generally from 8 to 10 miles. The highest and most imposing cliffs are found north and east of Agogebic Lake. Beyond Agogebic Lake the trap range widens and forms several ridges, between which it is not impossible that there may be sandstone. The Porcupine Mountains embrace a system of trappose rocks in three tolerably distinct ranges. All the country north of the northern edge of the trap range from the Ontonagon to the Montreal, with the exception of the trappose rocks of the Porcupine Mountains, is covered by the red sandstone of Lake Superior.

WHITNEY,[7] in 1848, finds in the townships near L'Anse fossiliferous limestone, which seems to be surrounded by and has been deposited on the Lake Superior sandstone.

FOSTER,[8] in 1848, in passing from Copper Harbor to L'Anse, finds that the trap, instead of being forced through the layer of sandstone, as on the northern slope of Keweenaw Point, protrudes through a fissure in it, causing an anticlinal axis. A few miles farther south the sandstone is nearly horizontal, being in a series of gentle undulations. At L'Anse the sandstones overlie the talcose, argillaceous, and hornblendic slates unconformably, while 15 miles southeast of L'Anse the granites protrude through these schists.

On Michigamme River were found, in order, beds of quartz and feldspar, hornblende, and specular oxide of iron, associated with talcose and argillaceous schists. On the left bank of the Michigamme (sec. 1, T. 46 N., R. 30 W.) is a hill 170 feet high which exposes a very large mass of nearly pure specular oxide of iron. About 40 feet from the escarpment is a metamorphic rock composed of rounded particles of quartz and feldspar with masses of ore intermingled like the pebbles of a conglomerate.

Iron ore and marble were observed along the Menominee, as well as various other kinds of rocks, including granite, hornblende slate, talcose slate, etc. At Sandy portage, on the Menominee, is a class of plutonic rocks older than the traps of Keweenaw Point, which were protruded among the slates and then denuded before the deposition of the sandstone; for the slates are intercalated among the igneous rocks with a vertical inclination, while the sandstone rests horizontally or nearly so upon them. This sandstone is regarded as the oldest of the Paleozoic rocks and is the equivalent of the sandstone on the northern slope of the Upper Peninsula. Resting upon this sandstone is a limestone which is sparingly fossiliferous.

WHITNEY,[9] in 1849, describes the iron ore of the Upper Peninsula of Michigan as existing in the form of solid ridges and knobs interstratified with banded jasper, the whole evidently of igneous origin.

JACKSON,[10] in 1849, describes the sandstone of Keweenaw Point remote from the trap as horizontal or but slightly waving, while near the trap rock it is as high as 30°. The conglomerate is limited to the borders of the trap and is of the same age as the finer grained sandstone with which it alternates. At the line of junction of the trap rocks and sandstone the two are interfused, producing the metamorphic rock amygdaloid, which resembles the vesicular lavas of volcanoes, but has its cavities filled with a great variety of curious and interesting minerals. On Isle Royal about one-quarter of the area is sandstone and conglomerate and the remainder trap, which forms ridges extending the whole length of the island.

JACKSON,[11] DICKENSON, MCINTYRE, BARNES, LOCKE, FOSTER and WHITNEY, GIBBS, HILL, BURT, and HUBBARD, in 1850, report upon the mineral lands south of Lake Superior in Michigan.

JACKSON,[12] in 1850, describes the red sandstones and conglomerates of Keweenaw Point as existing there anterior to the elevation of the trap rocks, being derived from the deposition of fine sand and pebbles from preexisting Primary rocks, such as granite, gneiss, or mica slate. Porphyry furnishes a large portion of the débris, but it is doubtful if this is not a semifused sandstone. There is no reason to believe that igneous agencies had anything to do with the origin of the pebbles of the conglomerate, for they are rounded by the action of water. From the circumstance that the conglomerate borders the trappean rocks it is supposed an ancient shore may have existed along that line. It is certain that the finer sandstone is more remote from the trap than the conglomerate is, and that it is less uplifted and inclined as it recedes from the trap band. Near the junction of the two rocks the strata dip 25° or 30°, while remote from it the sandstone is nearly horizontal. The mineral composition, association, and contents of the sandstone are identical with those of Nova Scotia, Connecticut, Massachusetts, and New Jersey, belonging to the New Red sandstone series; and that the Lake Superior sandstone belongs to this age has been confirmed by the discovery by C. F. Merion of a tract of limestone in the midst of the sandstone of Keweenaw Point near L'Anse. The limestone contains *Pentamerus oblongus*, and, according to Whitney, has a dip of 30°, while the overlying sandstone is horizontal and has been deposited around it. The sedimentary strata have undergone great change by the action of the trap rocks. Along the line of the junction a chemical combination of the materials of the sandstones and trap rocks took place, forming the vesicular trap called amygdaloid, while there has further resulted from this action a brecciated or trap tuff, consisting of broken pieces of amygdaloid and sandstone. At other times the sandstone is indurated into a flinty red rock resembling jasper. At the Copper Falls mine is a case of what appears to be an *Orthocera* in the breccia of amygdaloids and altered limestones. May it not have been torn from a subjacent bed of Silurian limestone by the agency of the intruded trap rocks? At the coast off Lac la Belle the sandstone in contact with trap has a dip to the south of 30°, while at Point Isabelle the sandstone cliffs are nearly horizontal.

Locke,[13] in 1850, finds, near L'Anse, that the trappean rocks contain fragments of slate distributed through it and converted into a hornstone when in small pieces, like the eruptive granite of Pigwacket Mountain, New Hampshire. At point No. 2, west of Presque Isle, is a junction of red sandstone and syenite. The mass of syenite intersected by dikes of trap is under the sandstone and seems to have but slightly affected it.

Foster and Whitney,[14] in 1850, accompany their synopsis of their explorations by geological maps of the region between Portage Lake and Montreal River, Keweenaw Point, Isle Royal, and the region between Keweenaw Bay and Chocolate River.

Whitney,[15] in 1850, finds the rocks in the district between Portage Lake and the Ontonagon River to comprise the following: First, the red sandstone of Lake Superior, the age of which can not be determined, as it is destitute of fossils. It lies directly upon the granite rocks. Second, a bed of fossiliferous limestone of the Lower Silurian system, which occurs in an isolated position and has but a limited extent, and the relations of which to the sandstone have not been determined with certainty. Third, the trappean rocks. Fourth, granitic and syenitic rocks, with hornblende and greenstone. The farther the red sandstone is removed from the trappean rocks, so much nearer do its strata approach to the horizontal and also become lighter in color and more fragile. The conglomerate of Keweenaw Point occurs mixed and intercalated in such a manner with the sandstone as to leave no doubt of their common origin and identity of age. In general the beds of conglomerate increase in frequency in nearing the trap. The sandstone does not repose directly on the trap, but almost invariably a bed of coarse pebble rock is found interposed between. A trap breccia found at Cushman's seems to be a product of the interfusion of trap and sandstone. Compact quartz rock or jasper occurs abundantly in mountain masses in the Porcupine Mountains.

Whitney describes a deposit of limestone which rises to a height of about 300 feet above the general level of the country near L'Anse. The limestone is indistinctly stratified and dips from zero to 30° at various points. At certain places it contains numerous fossils, but the greater part of the rock seems to be destitute of them. Among the fossils are encrinites, orthoceratites, and others. The country around is low and swampy, but the indications are for nothing but sandstone horizontally stratified. As the limestone is apparently inclined at an angle of 30°, it seems evident that this is the oldest rock, though it can not be denied that the stratification of the limestone is very obscure and in some places it appears to lie nearly horizontal. On the data collected the author feels unwilling to pronounce which is the older formation.

Foster,[16] in 1850, finds at Copper Harbor the junction of the trap and conglomerate. At the point of contact the trap is vesicular, but a few feet distant it is amygdaloidal. The conglomerate is made up of rounded pebbles of greenstone, porphyry, and rarely granite, cemented by a dark iron sand, with carbonate of lime among the interstices. Near the Quincy mine the conglomerate, or rather sandstone, containing quartz pebbles, forms the gorge of the stream below the falls, and differs essentially from that on the northern slope of Keweenaw Point. Between the sandstone and compact trap is a bed of red slaty trap associated with amygdaloid. At L'Anse sandstone and conglomerate are found resting unconformably upon chlorite slate, novaculite, or siliceous slate. In the Chippewa land district are found granite, gneiss, hornblende, chlorite, argillaceous slates, and magnetic iron ore. In sec. 1, T. 46 N., R. 30 W., is a bed of quartz composed of rounded grains, with small specks of iron disseminated, and large rounded masses of the same material inclosed, constituting a conglomerate. This bed is 15 feet in thickness and is succeeded again by a specular iron exposed in places to a width of 100 feet.

The author is disposed to place the sandstone of Lake Superior at the base of the fossiliferous series. The unbedded traps of Keweenaw Point and Isle Royal have broken through this sandstone, forming continuous lines of elevation. In receding from the trap of Keweenaw Point the inclination of the sandstone diminishes rapidly, and 5 or 6 miles away is nearly horizontal. In a fork of Torch River, on the Douglass Houghton Mining Company's land, the sandstone dips southerly, or away from the trap. On the north side of the stream it is seen resting on the trap in large blocks. On the south side of Keweenaw Point, at Bete Grise Bay, the sandstone is white and granular, destitute of pebbles, and dips southerly, or away from the trap. In the bottom of the bay, when the water is calm, the bands of sandstone can be seen describing immense curves parallel to the direction of the Bohemian range of mountains, and affording conclusive evidence that their bearing and upheaval are due to the protrusion of the igneous rocks. On the east side of sec. 14, T. 59 N., R. 29 W., the sandstone is nearly horizontal, although removed but a few miles from the trap.

Burt,[17] in 1850, finds on Keweenaw Point and along the south shore of Lake Superior to the mouth of Carp River and in the Porcupine Mountains five principal groups of rocks—Primary, slates, trap, conglomerate, and sandstone. With the Primary rocks are placed syenite and granite. Flanking the Primary rocks is argillaceous slate; flanking the slates and resting upon them are red and variegated sandstones, and these also flank the Primary rocks. The trap rocks have a much higher angle on the southeast than on the northwest side of the range, which runs from the northeast end of Keweenaw Point and extends in a course generally to the southwest. The conglomerate flanks the trap range on the northwest, and is made up of sand, pebbles, and small bowlders principally derived from the rocks of the trap family. Resting conformably upon the conglomerate rock is a series of alternating strata of sandstone and conglomerate.

Hubbard,[18] in 1850, finds, in the district south of Lake Superior, Primary and metamorphic regions, consisting of granite rocks, between which are metamorphic rocks which graduate into clay slates.

Burt,[19] in 1850, finds the area bounded on the north by the fifth correction line and south by the fourth correction line and Brule River, between ranges 23 and 37, granite and syenite, talcose and argillaceous slates, greenstone and hornblende slate, mica slates, coarse sandstone, calciferous sand rock, encrinal limestone, red sandstone and red clay, and magnetic iron-ore beds.

Foster and Whitney,[20] in 1850, give a systematic report on the geology and topography of the copper lands. On Keweenaw Point these consist of trappean rocks associated with conglomerates and sandstones.

On this point are two trap ranges, the southern known as the Bohemian Range. The conglomerates are volcanic friction rocks rather than the result of erosion. The pebbles may have received their rounded shape by being projected from fissures through water. The only instance in the district in which trap occurs remote from the lines of fissure is in the northeast corner of T. 49 N., R. 36 W., where

Silver Mountain rises as an isolated and dome-shaped mass to the height of 1,000 feet. The summit of the rock consists of labradorite and hornblende, while the surrounding plain is covered with clay, resting on sandstone in a nearly horizontal position. The sandstones and interbedded traps of Keweenaw Point and Isle Royal dip in opposite directions and form a synclinal trough. Near L'Anse is a limited patch of limestone which has a dip to the east of 25° to 30°, the limestone being distinctly stratified. The sandstone about a quarter of a mile to the north is horizontal, and it seems evident that the limestone overlies the sandstone, although the position of the inclined beds of the more southerly portion of the limestone is difficult to explain, since the surrounding country is low and level and underlain by sandstone and horizontal beds. It seems evident that at this point the country has been disturbed and upheaved by igneous action beneath, which has raised the strata without any appearance of trappean rocks at the surface. This is indicated by the fact that at no great distance to the south an elevation occurs at which the strata of sandstone dip on all sides, although there is no igneous rock visible. From the fossils entombed in this limestone Hall concludes that the rocks may be regarded as the equivalent of any of the following: The Potsdam and Calciferous sandstones, the Chazy, Bird's-eye, and Black River limestones, perhaps of the Trenton or even Hudson River groups. In T. 47 N., R. 25 W., Michigan, is a conglomerate, the pebbles of which comprise granite, hornblende, slate, greenstone, and iron ore.

Foster and Whitney,[21] in 1851, report on the iron region of the Lake Superior land district, and give an account of its general geology. The older rocks are classified as follows:

Formations.	Igneous (of various ages).	Plutonic rocks.	Granite.
			Syenite.
			Feldspar and quartz rock.
		Trappean or volcanic rocks.	Greenstone, or dolerite, porphyry, basalt, amygdaloid, hornblende and serpentine rocks, masses of specular and magnetic oxide of iron.
	Metamorphic (Azoic system).		Gneiss, mica and hornblende slate.
			Chlorite, talcose and argillaceous slate.
			Beds of quartz and saccharoidal marble.
	Aqueous (Silurian system).		

The igneous rocks are found in all these sedimentary systems. The oldest igneous rocks, consisting of hornblende, feldspar, and serpentine rocks, are contemporary with the Azoic system. The granites and syenites are intermediate in age between the Azoic and Silurian systems. These are traversed by two systems of greenstone dikes which are anterior to the purely sedimentary deposits. Contemporaneous with the lower portion of the Silurian system are the bedded traps and amygdaloids of Keweenaw Point, Isle Royal, and the Ontonagon region, which are composed of nearly the same constituents as many of the older igneous rocks, although there is no difficulty from the diversity in external characters in drawing the line of demarcation between them.

Below all the fossiliferous groups of the region is a class of rocks consisting of crystalline schists, beds of quartz, and saccharoidal marble, which is denominated the Azoic system, a term first applied by Murchison and De Verneuil to designate the crystalline masses which preceded the Paleozoic strata. This term as here used is limited to rocks which are detrital in origin and which have been formed before the dawn of organized existence. The general section shows the rocks of Keweenaw Point to be the counterpart of those of Isle Royal, except that the dip of the sedimentary rocks is reversed, thus rendering it highly probable that between these two points is a great curvature in the strata, caused by the elevation along the line of two volcanic fissures. The sandstone on the southern slope of the axis, equivalent to the Potsdam, is seen dipping away from the crystalline trap at a high angle, but at a short distance from the line of igneous outburst it verges toward horizontality; and along the coast at the head of Keweenaw Bay it is seen reposing unconformably on the slates of the Azoic system. From L'Anse to Chippewa Island in Menominee River, a direct distance of more than 80 miles, the country is occupied by rocks of the Azoic system, which include immense deposits of specular and magnetic oxide of iron, and are invaded at many points by igneous rocks, both granitic and trappean. At Chippewa Island the Potsdam sandstone reposes upon the upturned edges of the slates.

The Azoic rocks have been so transformed by direct and transmitted heat as to exhibit few traces of their original character. Sandstone has been converted into massive quartz, limestone into saccharoidal marble, and shales into hard crystalline schists. These rocks are destitute of life, are a system of obscurely stratified rocks interposed between the Potsdam and the granite, and are unconformable to the former in dip. The Azoic series of the southern shore have not been capable of division into two groups, as Logan divided the series on the north shore. The rocks are highly inclined and much contorted, and nowhere exhibit the characters of a purely sedimentary rock; but the evidences of metamorphism are more striking in approaching the lines of igneous outburst. Gneiss generally flanks the granite, succeeded by dark masses of hornblende, with numerous joints, but obscure lines of bedding, which often graduate into hornblende slate or chlorite slate in receding from the igneous products. The greenstones often form broad sheets, bearing the same relation to the slates that the trappean bands of Keweenaw Point bear to the conglomerates. Many of the slates appear to be composed of pulverulent greenstone, as though they might originally have been ejected as an ash and subsequently deposited as a sediment. They pass by imperceptible gradations from a highly fissile to a highly compact slate.

In sec. 19, T. 49 N., R. 27 W., are found a talcose and chlorite slate and quartzose rocks enveloping pebbles and displaying obscure lines of stratification. In sec. 32, T. 48 N., R. 26 W., and near Jackson Company's forge are found quartzose conglomerates. On the line between secs. 29 and 32, T. 47 N., R. 27 W., is a conglomerate forming an isolated rounded elevation, which is made up of coarse blocks of various sorts belonging to the neighboring trappean and slaty beds. Among them are found fragments of the rock associated with iron, and masses of the iron itself, and of the banded and jaspery varieties. Most of the fragments of the breccia are but slightly rounded and worn on their edges, having in this respect the appearance of a friction conglomerate. The blocks are cemented together by a hard ferruginous paste.

The granites belong to two epochs: The granite of the northwestern coast and the vicinity of Pigeon River was elevated before the Azoic period, since the upper portion of the slates repose horizontally around it; while that of the northeastern coast and that which forms the axis of the river systems of the two lakes were elevated after the termination of the Azoic period and before the dawn of the Silurian, since the granite has disturbed the upper beds of slate, while the lower beds of the Potsdam rest undisturbed around it.

The masses of iron ore and jasper have none of the characteristics of vein deposits. They are intercalated among the metamorphosed sedimentaries and have an intimate association with the trappean, porphyritic, and serpentine rocks. If the trappean rocks were an invariable accompaniment the ores would with little hesitancy all be assigned to a purely eruptive origin; but when they are found in the form of beds, in clearly metamorphic strata, having a common bearing and inclination, they are regarded as having been derived from the destruction of previously formed igneous masses, and their present association as having resulted from aqueous deposition. The Azoic period having been one of long-continued and violent mechanical action, there is no reason to doubt that many of the strata of which it is composed may have been derived from the ruins of previously formed rocks of the same age, both sedimentary and igneous, as is shown by the case of the knob of conglomerate already mentioned. The minute banding of the ore and jasper can hardly be explained by any other than the action of segregating forces in an igneous rock. The authors are then disposed to regard the specular and magnetic oxide of iron as a purely igneous product, in some instances poured out, in others sublimed, from the interior of the earth. Where the ores are in a state of purity, in the form of irregular masses in preexisting depressions, or where the incumbent strata are metamorphosed or traversed by the dikes of ferruginous matter, they are without doubt eruptive. Where impregnating metamorphic products, such as jasper, hornstone, or chert, quartz, chlorite, and talc slate are found, not only between the laminæ but intimately incorporated with the mass, giving it a banded structure, they are regarded as the results of sublimation. The supposition that the ore may be a secondary product resulting from the decomposition of a pyrite or the metamorphism of bog iron is inadequate to account for the accumulation of such mountain masses and to explain the relations to the associated rocks.

The bed of Lake Superior, embracing an area of about 32,000 square miles, is occupied almost exclusively by the Potsdam sandstone. The sandstone in the vicinity of the trappean rocks attains the enormous thickness of 5,000 feet, and often consists of conglomerates composed of trappean pebbles, while away from these lines of disturbance, where it abuts against the Azoic rocks, it is a purely siliceous sand. At Granite Point masses of granite are overlain by horizontal sandstones. The granites are cut by dikes of greenstone, which in no case penetrate the overlying rock. The same phenomena are seen at Presque Isle, at Middle Island below Presque Isle, and at Carp River. On Menominee River near the foot of Chippewa Island layers of sandstone are found on the upturned edges of the Azoic slates.

Whitney does not find the *Pentamerus oblongus* referred to by Jackson, nor any other form characteristic of the Niagara formation; but, on the other hand, they are pronounced as belonging to Lower Silurian types.

Foster and Whitney,[22] in 1851, repeat the general conclusions contained in their report on the iron region, and remark that the Azoic system is characterized by such immense deposits of specular and magnetic oxide of iron that it might with propriety be denominated the Iron Age of geology, while the Silurian epoch with equal propriety might be designated the Copper Age.

Foster and Whitney,[23] in 1851, further speak of the age of the Lake Superior sandstone. The sandstone of St. Marys River is traced to the south shore of Keweenaw Point and is found to increase in thickness gradually, until in the vicinity of the trappean rocks it becomes of great thickness, accompanied by wide belts of conglomerate. The conglomerates of Keweenaw Point are the result of igneous rather than aqueous forces, being caused by friction and mechanical volcanic action along the line of fissure. The mural faces of the trappean ranges are almost without exception turned toward the south, and the sandstone on that side is elevated at a high angle, sometimes dipping almost vertical at the junction of the two formations, but in proceeding southward becoming almost immediately horizontal. The appearance is as if the strata had been broken and elevated, just like the southern edge of the igneous mass. Where the sandstones and traps are interlaminated it is difficult to determine the junction when the sandstone lies upon the trap, but when below it the line of separation is sharp. As further showing that the sandstone is Lower Silurian, a small deposit of Lower Silurian limestone rests upon the sandstone; this effectually completes the chain of evidence.

Jackson,[24] in 1853, maintains that the red and gray sandstones of Lake Superior are above the rocks of Devonian age. They rest horizontally around Silurian limestone, which has an inclination on Sturgeon River near Keweenaw Point of 30°. In point of fact the sandstones of Lake Superior are the exact equivalents of those of Nova Scotia, where trap rocks of the same age as those of Lake Superior pass through them. The amygdaloidal trap of Keweenaw Point and Isle Royal is a vesicular rock formed by the interfusion of sandstone and trap rock.

Jackson,[25] in 1860, again asserts that the red sandstones of Keweenaw Point are certainly coeval with the sandstone of Nova Scotia, Connecticut River, and New Jersey, as proved by identity of composition, mode of disruption, character of associated minerals, and, above all, by the fact that they rest upon Devonian limestones. *Orthoceratite* at Copper Falls mine and *Pentamerus* in the underlying limestone of Sturgeon River show that the sandstones are not Potsdam. This is also shown by the occurrence of pitchstone porphyry on Isle Royal such as is found in the Isle of Arran of Triassic or Devonian age. The author is not disposed to place the sandstones of the Pictured Rocks in the same formation with Keweenaw Point and Isle Royal.

Rogers,[26] in 1860, maintains that the argillaceous shales and conglomerates of a part of the southern shore of Lake Superior are the equivalent of the Primal series. The Cupriferous series is in direct association with the Potsdam, and therefore the argument for Triassic age on account of texture and color is entirely valueless.

Winchell (Alexander),[27] in 1861, gives a general sketch of the geology of Michigan. Among the stratified rocks are placed the Azoic, while the unstratified rocks are divided into Volcanic, including lava, trap, etc., and Plutonic, including granite, syenite, etc. The Azoic rocks are of immense thickness and are interposed between the crystalline, plutonic, and volcanic rocks and the Lake Superior sandstone. The rocks in this system in Michigan consist of talcose, chloritic, and siliceous slates, quartz, and beds of marble. In it are found the specular and magnetic ores of Lake Superior. The Lake Superior sandstone is placed in the lower Silurian system. The solid quartzose character of the rock of St. Josephs and Sulphur islands suggests the idea that it is Azoic; but the gradual transition from the unaltered sandstone of the Sault to the altered sandstone of Neebish Rapids and the jasper conglomerates of the western shore of Campement d'Ours, favors the equivalency of the sandstone and the quartzite, as does also the fact that the fossiliferous Chazy limestone is found directly upon the quartzite at Sulphur Island.

WILLIAMS and BLANDY,[28] in 1862, describe the trap ranges of Portage Lake as being about 3 miles wide and consisting of amygdaloidal trap, occasionally intercalated with sandstones and conglomerates. The dips vary from 60° to 75°, becoming more nearly horizontal toward the northwest; until finally the sandstone which succeeds it becomes absolutely horizontal.

KIMBALL,[29] in 1865, divides the rocks of the Marquette region into two formations, Laurentian and Huronian, the former including the granite ridges, while the latter nearly agrees with Foster and Whitney's limits for the Azoic. The crystalline rocks south of Keweenaw Point are pre-Paleozoic, while the greenstones of that point are intercalated conformably with the Paleozoic. The specular iron ore and beds of specular conglomerate are heavy-bedded strata and schists in which none of the phenomena of aqueous deposits are wanting. They exhibit not only stratification, but anticlinal and synclinal folds. From a stratigraphic point of view the Huronian greenstones, schists, and iron ores of Marquette exhibit characters which render quite untenable the theory of the exotic character of any portion of them.

AGASSIZ,[30] in 1867, finds at two ravines near Torch Lake—one the Douglass Houghton—that the sandstone rests unconformably upon the trap. The trap dips 42° N., while the sandstone, 100 feet distant, lies nearly horizontal, with no trace of an anticlinal axis between.

The sandstone contains waterworn fragments of the trap. The sandstone north of the range is conformable with the trap, but the sandstone south is plainly of a different age.

CREDNER,[31] in 1869, describes the Laurentian and Huronian systems in the Upper Peninsula of Michigan. The Laurentian system is the gneiss granite formation, which includes many varieties of massive rocks, as well as hornblende, chlorite, and other schists, and also thin layers of dolomitic limestones. The Huronian system is the iron-bearing formation. The general succession, beginning at the base, is: Quartzite, in its upper parts often iron stained, 2,500 feet; crystalline dolomitic limestone, containing argillite, chlorite schist, and layers of quartz, seldom conglomeratic, 2,500 to 3,500 feet; more or less siliceous hematite, 600 to 1,000 feet; ferruginous chlorite schist, 1,200 feet; dark clay slate, with beds of hard quartzite, 8,500 feet; chlorite schist, with beds of diorite, 1,300 feet; talc schist, with various impurities, 100 feet; aphanitic to granular diorite, 2,300 feet; talc schist, with various impurities, 1,500 feet.

In the iron group is a granite dike on Sturgeon River 12 feet wide, which breaks through the iron ore and jasper at a right angle to the schist. Over the iron formation, at the Michigamme mine, is found a conglomerate of jasper and fragments of quartz in an iron and quartz base. There is a discordance between the Laurentian and the Huronian. The Potsdam sandstone rests upon the Huronian and Laurentian unconformably.

Brooks and Pumpelly,[32] in 1872, maintain that the copper-bearing rocks of Lake Superior are unconformably below the Lower Silurian sandstone. This is shown by the fact that the horizontal strata abut against the steep faces of the cupriferous series on Keweenaw Point, the latter dipping away from the sandstone at an angle of 60° to 40°. Also for a long distance between Montreal River and Lake Gogebic the cupriferous series conform in strike and dip to the Huronian schists, dipping steeply to the north at an angle of 50° to 70°, while the Silurian sandstone to the north, in a flat-lying condition, covers an extensive country. In sec. 13, T. 46 N., R. 41 W., the Silurian sandstone is found in a nearly horizontal position, while 4 miles distant the cupriferous series dip to the north at an angle of 50°.

It is concluded that the cupriferous series was formed before the tilting of the Huronian beds upon which it rests conformably, and consequently before the elevation of the great Azoic area. After the elevation of these rocks, and after they had assumed their essential lithological characters, came the deposition of the Lake Superior sandstone and its accompanying shales as a product of the erosion of the older rocks, and containing fossils which show them to belong to the Lower Silurian. At several places in the Upper Peninsula of Michigan a lack of conformity between the Laurentian and the Huronian has been detected, but when the Huronian and the Cupriferous are seen in contact there seems to be a well-marked concordance between them.

Brooks,[33] in 1873, divides the rocks of the Upper Peninsula, in descending order, into Lower Silurian, Copper-bearing rocks, Iron-bearing rocks, and Granitic rocks, and gives a systematic account of the last two, and especially of the economic geology of the iron-bearing series. The copper-bearing rocks correspond with the Upper Copper-bearing rocks of the Canadian geologists and occupy a narrow belt on the northwestern edge of the Upper Peninsula. This series includes sandstones which are nearly or quite identical with the Silurian in appearance, but their great mass is made up of different varieties of trap, often amygdaloidal, interstratified with beds of peculiar conglomerates. The layers of these rocks are inclined, dipping northwest and north toward Lake Superior, from vertical to as low as 23° on Keweenaw Point. The iron-bearing rocks are assumed to correspond with the Huronian system of Canada. They may have a thickness of 5,000 feet and consist of a series of extensively folded beds of diorite, quartzite, chlorite schists, clay slate, mica slate, and graphitic shales, among which are intercalated extensive beds of several varieties of iron ore. The most abundant rock is greenstone or diorite, in which the bedding is usually obscure, but the intercalated schists and slates usually bear strong marks of stratification. The dips are usually at a high angle and are more apt to be north or south than any other direction. The granitic rocks are believed to be the equivalents of the Laurentian of Canada. In these the bedding indications are still more obscure and often entirely wanting. Also, if possible, there is more irregularity in strike and dip than in the Huronian.

A full lithological description of the different phases of rocks found in the Huronian system, and the various sections at the many mines in the Upper Peninsula, are given in detail.

The formations of the Huronian system in the Marquette region comprise nineteen members, numbered from the base upward. I, II, III, and IV are composed of beds of siliceous ferruginous schist, alternating with chloritic schists and diorites, the relations of which have not been fully made out; V is a quartzite, sometimes containing marble and beds of argillite and novaculite; VI, VIII, and X are siliceous ferruginous schists; VII, IX, and XI are dioritic rocks, varying much in character; XIII is the bed which contains all the rich specular and magnetic ore, associated with mixed ore and magnesian schist; XIV is a quartzite, often conglomeratic; XV is argillite or clay slate; XVI is uncertain—it contains some soft hematite; XVII is anthophyllitic schist, containing iron and manganese; XVIII is doubtful; XIX is mica schist, containing staurolite, andalusite, and garnets. The thickness of the whole Marquette series may aggregate 5,000 feet.

The beds appear to be metamorphosed sedimentary strata, having many folds or corrugations, thereby forming in the Marquette region an irregular trough or basin, which, commencing on the shore of Lake Superior, extends west more than 40 miles. The upturned edges of these rocks are quite irregular in their trend and present numerous outcrops. While some of the beds present lithological characters so constant that they can be identified wherever seen, others undergo great changes. Marble passes into quartzite, which in turn graduates into novaculite.

Near the junction of the Huronian and Laurentian systems, in the Marquette region, are several varieties of gneissic rocks, composed in the main of crystalline feldspar, with glassy quartz and much chlorite. Intersecting these are beds of hornblendic schist, argillite, and sometimes chloritic schist. These rocks are entirely beneath all of the iron beds, seem to contain no useful mineral ores, and are of uncertain age. No attempt is here made to describe or classify them.

The diorites, dioritic schists, and related rocks range in structure from very fine grained or compact (almost aphanitic) to coarsely granular and crystalline, being sometimes porphyritic in character. The rock passes on the one hand into a hornblende rock and on the other into a rock resembling a diorite. It is eminently schistose in character, splitting easily, and appearing more like chloritic schist than any other rock. At several points dioritic schists, semi-amygdaloidal in character, were observed, and in one instance the rock had a strong resemblance to conglomerate. The bedding of the rocks is generally obscure, and sometimes entirely wanting. It is only by a full study of the rock in mass and its relations to the adjacent beds that one becomes convinced, whatever its origin, that it presents in mass precisely the same phenomenon as regards stratification as do the accompanying schists and quartzites. Chloritic magnesian schists are associated with the pure and mixed ores. Oftentimes these magnesian schists several feet in width cut across the stratification, and are called slate dikes. It is difficult or impossible to draw the line between these magnesian schists and the dioritic schists. It is suggested that on the New England-Saginaw range and at the Lake Superior mine tepid alkaline waters have penetrated the formation and have dissolved out the greater portion of the siliceous matter, leaving the iron oxide in a hydrated earthy condition.

At the S. C. Smith mine and along Plumbago Brook is found carbonaceous matter. These carbonaceous shales burn white before the blowpipe and mark paper like a piece of charcoal.

Above the Cascade ore is a bed of coarse conglomerate. The upper quartzite of Republic Mountain, near its base, is a conglomerate containing large and small fragments of flaggy ore. At the New England mine, between the ore and the quartzite is a mass of specular conglomerate similar to that at Republic Mountain.

The iron-bearing series is unconformably above the older Laurentian rocks. The contact is observed in Plumbago Brook, where a talcy red rock, unmistakably belonging to the Huronian, dipping at a low angle to the northwest, is in contact with the Laurentian chloritic gneiss, which dips at an angle of about 35° SSW. The same phenomena can be seen near Republic Mountain, where the Huronian schists strike nearly at right angles to the Laurentian gneiss, only 50 feet distant; both series dipping at high angles, the Laurentian east of north, and the Huronian about 45° west of north. The nonconformability is further shown by the fact that the Laurentian generally abounds in dikes of granite and diorite, which are almost entirely absent from the Huronian.

Many details are given as to the Menominee and Felch Mountain districts. The rocks of these ranges are parallel with those in the Marquette district. At many places the Silurian rocks unconformably cap the iron-bearing rocks.

The Lake Gogebic and Montreal River iron range is regarded as an eastern prolongation of the Penokee range of Wisconsin. The northern geological boundary is the south copper range, consisting of massive and amygdaloidal copper-bearing traps, the bedding of which is exceedingly obscure, with occasional beds of sandstone and imperfect conglomerates. The strike of these rocks is east and west, with a dip to the north at a high angle, thus conforming with the Huronian rocks underneath. On the south of the iron-bearing rocks is a series of granites, gneisses, and obscure schists, which are unmistakably Laurentian in their lithological character, and they are unconformably overlain by the Huronian rocks. The horizontal Lower Silurian sandstones occupy a broad belt of country north of the copper range. Their actual contact with the highly tilted copper rocks was not seen, but they show not the slightest evidence of disturbance within a few miles of these steeply inclined rocks, and are regarded as unconformably above them.

PUMPELLY,[34] in 1873, gives a systematic account of the copper-bearing rocks. These on Keweenaw Point consist of an immense development of alternating trappean rocks and conglomerates dipping to the northwest at an angle running from 60° to 23°. The red sandstone and shales of Lake Superior are everywhere nearly horizontal on the south shore of Lake Superior between the Sault Ste. Marie and Bete Grise Bay. At the western edge of this belt its nearly horizontal strata abut against the steep face of a wall formed by the upturned edges of beds of the cupriferous series of melaphyre and conglomerate, which dip away from the sandstone at angles of 40° to 60°. This sharp line has been explained as due to a fault, the horizontal sandstone being regarded as of the same age as the conformable overlying sandstone of the cupriferous series. One objection to this explanation is the enormous amount of dislocation required, amounting to several miles. Again, near Houghton there are two patches of sandstone lying on the upturned melaphyre beds. In the horizontal sandstone near the so-called fault are abundant pebbles of melaphyre and conglomerate of the cupriferous series. But the most decided facts found by Major Brooks and the author are in the country between Bad River in Wisconsin and the middle branch of the Ontonagon, east of Lake Gogebic. Here the quartzites and schists of the Huronian formation are bordered on the south by the Laurentian gneisses, and are overlain conformably by the bedded melaphyres and interstratified sandstones of the cupriferous series. Between these ridges, forming the south mineral range and the main range of

Keweenaw Point, is the horizontally stratified Silurian sandstone, forming a generally level country. The conformable cupriferous and Huronian schists dip to the northward at angles of 50° to 70°, but in approaching Gogebic Lake from the west the pre-Silurian erosion has made a deep indentation across the cupriferous series and the Huronian, as well as into the Laurentian, so that a short distance west of the lake these rocks end in steep and high declivities, at the base of which lies the level country of the Silurian sandstone. On Ontonagon River the Silurian sandstone is nearly horizontal, while about 150 steps from the base of the cliff are outcrops of Laurentian schists having a dip of 45° to 60° SE. The nearest outcrop of the cupriferous series is about 4 miles distant, and it strikes nearly east and west and dips 50° N. The lithology of the copper-bearing rocks of the Portage Lake district is fully given. The rocks are melaphyres and amygdaloids, interstratified with conglomerates. The paragenesis of the minerals associated with the copper is worked out. Several detailed cross sections at Portage Lake are given, and one cross section at the Central mine describing the thickness and character of the alternating rocks in great detail.

MARVINE,[35] in 1873, gives in the greatest detail the structure and lithology of the alternating trappean and detrital beds of the copper-bearing rocks on the Eagle River section. The correlation of the Houghton and Keweenaw rocks is fully discussed. The Albany, Boston, and Allouez conglomerates are regarded as the same bed. Stratigraphically eleven out of fifteen conglomerates have equivalents in both the Houghton and the Keweenaw regions. The conglomerate beds of Keweenaw Point are not mere local deposits, but are unusually persistent, and while a bed may thin out and lose its character as a conglomerate, it may still exist as a mere seam. In one instance a band extends for at least 50 miles, varying in thickness from a few to more than 75 feet. It is therefore concluded that the changes which formed the melaphyres ceased to act over extended areas during the time of the formation of the sandstones and conglomerates. The abundance of acidic rocks among the conglomerates was noted, and opposite Calumet the former presence of predominant quartz porphyry was inferred.

ROMINGER,[36] in 1873, places the Lake Superior sandstone as Potsdam, finding it directly overlapped by the calciferous formation. At Presque Isle and Granite Point the horizontal sandstones are found resting upon the crystalline rocks, there being at the former place a conglomerate which rests unconformably upon the dolomite of Presque Isle. The sandstones on the eastern shore of Keweenaw Point retain their horizontal position and lithological character to such a degree that the different strata can be parallelized without difficulty with those of the more eastern localities. Near the center the horizontal sandstones are found abutting against the uplifted edges of a different rock series, the copper-bearing rocks. The abrupt edges of the strata look to the southeast, and their dip is in the opposite direction at angles varying from 70° to 40°. The unconformable abutment of the sandstones against the trappean series is plainly observed at several places near Houghton, on the property of the Isle Royale Company, near the stamp works of the Calumet and Hecla mines, on the railroad coming down from the mines to the stamp works, and on the Sheldon and Columbia property.

ROMINGER,[37] in 1876, describes the red Lake Superior sandstone as unconformably abutting against or overlapping the trap rock with horizontally disposed layers. On the western slope of the ridge the trap rocks are conformably overlain by sandstones, conglomerates, and slates, the age of which is intermediate between the trap and the horizontal sandstone, but between all three there are such great lithological affinities that it is natural to regard them as consecutive products of one and the same epochs. The absence of trappean rocks distinguishes the upper division from the lower.

The Huron Mountains are a crystalline granitic and dioritic Laurentian rock series. These granitic rocks are surrounded by a narrow belt of the horizontal red sandstone of Lake Superior, which abuts unconformably against them. The Huronian rock series, with uplifted beds alternating with slate rocks, quartzites, diorites, and jaspery strata, with seams of iron ore, lean unconformably against the granitic series.

BROOKS,[38] in 1876, places granite as the youngest Huronian rock south of Lake Superior. This granite occurs as the uppermost member of the Menominee and Penokee series, but in the latter it thins out and disappears before reaching the Gogebic region. The lithological character of this granite belt bears a general resemblance to the Laurentian rocks. This granite, from the fact that it does not give off dikes cutting the copper-bearing series, is believed to be earlier than the latter. Although there is approximate conformability in strike and dip, there is probably an unconformity between the copper-bearing rocks and the Penokee-Gogebic Huronian, as shown by the fact that the former series is in contact in different places with various members of the Huronian. There is also an unconformity between the Huronian and the Laurentian.

As supporting the view that the pre-Silurian systems are distinct periods, attention is called to the lithological differences between the three series, as well as to the intensity of folding to which they have been subjected. The detrital members of the copper-bearing series consist of friable sandstone showing no greater metamorphism than the Silurian, and it is folded only in regular magnificent sweeps, the same strike and dip continuing in some cases for about 150 miles. The Huronian series consists of greenstones, various schists, clay slates, quartzites, marbles, with gneisses and granites containing no copper, and having conformable beds of the various oxides of iron, and is everywhere sharply folded into narrow troughs and irregular basins trending in every direction. The Laurentian is still more plicated and metamorphosed, the stratification often being entirely obliterated. Whether the Laurentian rocks can be separated into two or more nonconformable systems, as in Canada, no opinion is ventured. Since Keweenaw Peninsula is a striking geographical feature in Lake Superior, and is the locality where the copper-bearing series is best exposed, the name Keweenawian is suggested for this period.

BROOKS,[39] in 1876, gives a list of the rocks of the Huronian series in the order of their abundance and as they occur in stratigraphical succession in the Marquette, Menominee, Penokee, and Gogebic series. Lithologically the rocks are divided into (1) fragmental rocks, exclusive of limestone; (2) metamorphic rocks not calcareous; (3) calcareous rocks; (4) igneous rocks.

The fragmental rocks include quartz conglomerates, which occur in the middle horizon, in both the Marquette and the Menominee and in the latter at the base of the series, where it holds pebbles of granite, gneiss, and quartz. In the metamorphic rocks not calcareous are included many varieties; the mica-bearing series includes granite, syenite, gneiss, mica schists, hornblende schists, mica slates, clay slates, diorites, diabases, quartzites, siliceous schists, chert and jasper rocks, iron ores, as well as many others. Among the eruptive rocks is a feldspathic series, including granite dikes; hornblendic and pyroxenic series, including diabase and similar rocks; and hydrous magnesian schistose rocks which are found in dikelike forms crossing the quartzites, iron ores, and greenstones.

The succession in the Marquette region from the base upward is (*a*) syenite, diorite, diabase, hornblende schists, slates, conglomeratic quartzites, and various quartzose iron ores; (*b*) quartzite graduating into protogine and containing interstratified beds of dolomitic marble; (*c*) ferruginous quartzose schist; (*d*) hornblendic rocks with greenstones; (*e*) ferruginous quartzose flags, clay slates, and quartzites; (*f*) hornblendic rock related to diorite and diabase; (*g*) siliceous hematitic and limonitic schistose ores; (*h*) diorite, hornblende schist, and chlorite schist; (*i*) arenaceous quartz schist, banded with micaceous iron and quartzose limonitic ore; (*j*) pure specular hematite and magnetite, with banded jaspery schists and interstratified beds of chloritic and hydromica schist; (*k*) an arenaceous quartzite, often semischistose and conglomeratic; (*l*) argillaceous slate; (*m*) quartz schists; (*n*) anthophyllitic schist; (*o*) mica schist. Similar successions are given in the other regions mentioned and correlated with that in the Marquette region, and all of these successions are compared and correlated with Logan's succession in Canada.

The Huronian in the Marquette, Menominee, and Gogebic regions is nonconformable with the Laurentian.

Pumpelly,[40] in 1878, describes Lake Superior as divided into two distinct basins by Keweenaw Point, the western basin being a geosynclinal trough. The southeastern lip of this trough consists of an immense development of volcanic rocks in the form of great beds and flows associated with conglomerates and sandstones, both of which consist essentially of porphyry detritus. This Keweenaw series is more nearly conformable with the underlying highly tilted Huronian schists than with the Potsdam sandstone. The prominent eruptive rocks of the Keweenaw series fall under the two heads, diabase and melaphyre. The changes which have taken place in the interior of the rock masses since eruption, that is, the metasomatic development of these rocks, is traced out in great detail.

Wright,[41] in 1879, describes the Laurentian series as consisting of coarsely crystalline massive granites, passing into gneissoid rocks, and these graduating into mica schists, and the latter even as imperceptibly into slates. The Laurentian granite is regarded as a metamorphic sedimentary rock, because the quartz grains contain cavities filled with liquid, while igneous granites never contain such cavities, but rather those filled with glass or stone. The Lower Huronian strata have been chiefly derived from the ruins of the Laurentian rocks. The nonconformity between the Laurentian and Huronian may be seen at Penokee Gap. Here the dip of the gneissoid granite is about 70° S., while the plainly bedded Huronian strata in direct contact have a dip of 65° N. At the Macomber mine, near Negaunee, is found a bed of manganiferous hematitic shale bearing the impression of some fossil which Brush, Verrill, Dana, and Smith pronounce to belong to the lower forms of life. The Lower Silurian sandstone about the city of Marquette is nearly horizontally bedded, and rests unconformably on and against the Huronian.

Brooks and Wright, in 1880, discuss the geology of the Menominee iron region in Wisconsin. See section 2, Wisconsin, pages 188–190.

Wadsworth,[42] in 1880, gives notes on the geology of the iron and copper districts of Lake Superior. The contacts of the jasper and ore, which are interlaminated and have a common origin with the associated schists, are described, and at numerous points the contacts are found to be those of eruptive and sedimentary. The schistose structure is regular, while the jasper and ore is exceedingly contorted, breaks across the schistose and other rocks, and contains fragments of the schists. Not the slightest sign of plasticity or intrusion of the schists relative to the ore and jasper was seen. The present lamination of the schists existed prior to the intrusion of the ore. At the School-house, New York, and Jackson mines the overlying rock contains débris of the underlying ore and jasper. The diorites, felsites, and diabases are intrusive rocks. The soft hematites differ from the hard ore and jasper only in that they have been leached by thermal waters and changed to their soft condition. The granite is found at numerous points to cut the schists and gneisses. At several places, also, it cuts a quartzite, one of which resembles the ordinary Huronian quartzite. The crystalline rocks of Presque Isle are peridotite and serpentine which has resulted from the alteration of the peridotite.

The only evidence that the Huronian unconformably overlies the Laurentian is the fact that the foliation of the latter does not conform in its dip to that of the former. However, no point was found in which it was possible to trace the rock continuously from well-marked and mapped Laurentian into the Huronian. The general structure of the iron region seems to be as follows: The schists and sandstones were laid down in the usual way, and were then disturbed by the eruption of the jasper and ore. Much of the original rock still remained horizontal, and new sedimentary deposits continued to be formed out of the jasper and other rocks. Next came the eruption of the diorite, which completed most of the local folding and tilting of the strata. Finally the granite eruption took place on both sides of the Huronian, uplifting and contorting the strata near it, and perhaps laterally compressing the inclosed iron-bearing rocks.

The conclusion reached by Foster, Whitney, and Marvine that the traps and lava flows were successively laid down one upon the other, and covered by sandstones and conglomerates, is agreed with. The sandstones and conglomerates when overlain by traps are usually baked and indurated. At the Douglass Houghton ravine and Hungarian River the Eastern sandstone, which it has been maintained rests against the trap and sandstone series unconformably, is found interlaminated with the melaphyres, and this settles the long-disputed question of the relative age of the traps and Eastern sandstone of Lake Superior. The last melaphyre sheet which underlies the sandstone has a dip to the northwest of 20°. As the Douglass Houghton ravine is followed downward the dip, although still to the northwest, gradually declines in steepness, the last dip measured being 5°. The junction between the Eastern sandstone and the trap, described by Agassiz and Pumpelly, is not the junction at all, it being some distance below instead of at the falls. In the Torch Lake sandstone quarry the sandstone layers, instead of being horizontal, as they have been regarded, have a dip of 15°, the former supposed bedding being due to joints. As the Eastern sandstone conformably underlies the traps, the Eastern and Western sandstones and the traps lying between them are of the same geological age.

Rominger,[43] in 1881, gives a general account of the Marquette and Menominee iron region, with very voluminous details as to particular localities.

Marquette region.—In general remarks on the geology of the Marquette district the succession is said to be: (1) Granitic group, (2) Dioritic group, (3) Quartzite group, (4) Iron group, (5) Arenaceous Slate group, (6) Mica schist group, and (7) Serpentine group; but later it is seen that the Quartzite group reposes upon the Iron group, so that the order of 3 and 4 is reversed. The Silurian sandstones rest horizontally on the other rock formations and frequently contain fragments of the underlying formations. The crystalline granitic masses are directly confined to the northern and southern limits of the Marquette district. The dip of the strata on the south side of the trough is usually to the north, and on the north side to the south, so that we may consider this area as a synclinal caused by the upheaval of its northern and southern margins. The granitic and sedimentary rock masses are traversed by rock belts of a crystalline character, which represent lava streams intruded at different periods.

In the Granitic group the granites are found interstratified with the Huronian schists of the Dioritic group. The granites are usually middling coarse grained and in the main are massive, although distinct gneissoid rocks have a limited occurrence. Besides the dioritic dikes there are in the granites crystalline nonstratified masses resembling eruptive dikes. In several instances granite dikes show a laminar arrangement of the mica scales. Also syenites are associated with the ordinary granites. The hornblende rocks associated with the granites are distinguished from those occupying a higher position in the series by the brighter luster of the hornblende crystals. Dioritic rocks occur interstratified with the granites, which are probably of the same origin as the volcanic eruptives. In the Laurentian rocks no limestones, layers of quartzite, nor beds of iron ore are found. The granitic rocks in their present position are actually the younger rocks, as shown by the intrusion of large masses of granite between the stratified sediments of the Dioritic group.

The Dioritic group is regarded as remelted, completely metamorphosed Huronian sediments, their more crystalline character being due to their closer proximity to the volcanic forces. The rocks of the Dioritic group include a large succession of schistose beds of uniform character, interstratified with massive diorite. In the dioritic rock chlorite frequently replaces the hornblende and often seems to be a product of its decomposition. The massive diorites are usually conformably bedded with the schists, and often insensible gradations from the schistose conditions to the massive diorite can be seen. The exposures of massive diorite generally form a nucleus around which the inclosing rock masses are arranged concentrically with a more perfect schistose structure. In the Dioritic group are conglomerates. One variety is well exposed at Deer Lake furnace, where the pebbles are of a feldspathic substance which on fresh fracture contrasts little with the surrounding schistose mass. Also extensive conglomeratic masses are found full of granite pebbles of large size in sec. 2, T. 48 N., R. 26 W., and in sec. 29, T. 48 N., R. 25 W. In opposition to Brooks it is maintained that there is but one Iron-group formation.

The Quartzite group is in places interstratified with ferruginous and siliceous seams, as well as novaculitic strata and siliceous limestones. Frequently in the quartzite is a conglomerate containing abundant quartz fragments, and also not infrequently containing granite and slate fragments. Oftentimes these conglomerates containing the granite fragments are very close to the massive granite, while it not infrequently underlies them. At one place in which the quartzite is in contact with the granite the one rock is seen to graduate by imperceptible stages into the other, in which case the sedimentary strata are changed into the granite-like rock by being exposed to the contact with the eruptive granite. In another place a granite breccia containing large fragments of granite is found in connection with such large masses of granite as to be too great to be fragments of a breccia, and this suggests that the nucleus of the hills are solid granites, whose shattered portions are recemented on the spot by sedimentary débris washed into the interstices. In the next hill to the south the inclosed water-worn pebbles are in part granite and in part slate. Above the ore-bearing rock beds is generally a very coarse quartzite conglomerate which often has the characters of a coarse-grained ferruginous quartzite and grades down into a brecciated ore. The fragments are chiefly ore, jasper, and quartz, and the cement is arenaceous or ferruginous. This occurrence is so general as to suggest that great disturbances not of a local extent must have occurred at the end of the era of iron sediments. The number of localities and mines at which this conglomerate or breccia occurs is very great. Among the latter are the Home, Gibbon, Jackson, Cleveland, Cascade, Gribben, Salisbury, Lake Superior, Champion, Saginaw and Goodrich, Keystone, Republic, and Michigamme.

The Iron group occupies a position inferior to the Quartzite group, and there are not two horizons here, as supposed by Brooks. It is composed of banded jasper, conformable chlorite schist, and ore. The ore deposits are not regular sedimentary layers, but the product of the decomposition of the impure ledges by percolating waters leaching out the siliceous matter and replacing it with iron oxide, and are therefore very irregular in form. The strata are in a much disturbed condition, folded and distorted in every possible way, usually without faults. These disturbed beds lie in every instance directly, but often unconformably, on chloritic or hydromicaceous schists, or on crystalline dioritic masses, which are constant associates of the chlorite schists, or on dioritic schists. At the Jackson mine are knobs of diorite associated with schists surrounded by the banded jasper rocks, which are evidently corrugated by the intrusion of this mass. In places the ore-bearing formation is not found incumbent on the Dioritic group. At Teal Lake the quartzite is found under the ore and the diorite over the ore, which leads to the conclusion that these strata are in an overturned position.

The Arenaceous slate group, of great thickness, is so designated because a large portion of the rocks here included consist of sandy siliceous layers, alternating with slaty argillitic rock beds and occasionally with compact quartzite. The strata in different localities often differ considerably. The rocks of this group are incumbent on the quartzite formation, but also sometimes rest upon the ore-bearing rocks, and often are found in direct contact with the dioritic series. The rocks are sometimes conglomeratic or brecciated, the fragments consisting of different kinds of rocks. In the black roofing slates of Huron Bay the cleavage is discordant with the bedding. Occupying a position above the black slates are the ore deposits of the Taylor mine, near L'Anse, and of the Northampton and D'Alaby, north of Champion; also the S. C. Smith and other mines. These ores are contemporaneous and equivalent to that of the Commonwealth in the Menominee district.

The Mica schist group is found exposed for the most part about Michigamme village. The Serpentine group includes the rocks of Presque Isle and those of similar class. The Silurian sand rock reposes unconformably upon the Serpentine formation at Presque Isle. Besides the serpentine and other magnesian silicates, limestone comprises an important share of this group.

The seven previous groups, considered to be a succession of sedimentary strata, are intersected by various dikes, among which are a dioritic rock and dolerite dikes, the latter of which are later in age than the former. No proof has been found of any discordance between the granites of Marquette and the adjoining Huronian beds. On the contrary, outcrops of the two kinds of rocks exhibit a remarkable parallelism in strike and dip, and in many localities the Huronian schists and belts of granite are interlaminated in perfect conformity. The granite is, however, regarded as intrusive masses. The granites are therefore, with reference to the stratified sedimentary rocks, actually the younger rock.

Menominee region.—Many localities and sections in the Menominee iron region are described in detail. The Silurian sandstone is found to rest unconformably upon the nearly vertical Huronian strata. Near Sturgeon River Falls, in the river, the quartzite formation reposes unconformably on the granite. Thick layers of limestone are found in the series, and this is sometimes conglomeratic. The fissile phyllite schists are found in discordance with the dioritic schists at Lake Hanbury. The granitic and gneissic rocks south and north of the Felch Mountain ore formation are found to be absolutely identical. The dioritic rocks are found generally and play the part of an intrusive with regard to the strictly sedimentary rock beds of the Huronian series. The Dioritic group is held to be older than the Iron group because it exhibits a greater degree of metamorphism and on the ground that it is lithologically like the equivalent Dioritic group of the Marquette district. It has evidently been transformed under the cooperation of heat and partially brought into a plastic condition.

In the eastern part of the Menominee region the rocks found comprise, in descending order, the Lake Hanbury slate group, perhaps 2,000 feet in thickness; the Quinnesec ore formation, which comprises micaceous and argillitic strata containing ore bodies, not less than 1,000 feet thick, and the Norway limestone belt, at least 1,000 feet thick. The Commonwealth mine, in the western part of the Menominee district, represents a higher horizon than the Quinnesec ore formation.

ROMINGER,[44] in a report of the Michigan Survey for 1881 to 1884 (published in 1895), further discusses the complex described in the former volume as the Huronian system. The lower granite and gneissoid portion of the rock groups in the Marquette region exhibits the characters of an eruptive and not of an altered sedimentary rock. Generally a solid crust of granite probably served as a substratum on which the Huronian sediments were laid down, but an opportunity is not often afforded to see the rocks in contiguity well enough exposed to allow a discrimination as to whether such contact is an original primary one or resulted from dislocation. The existence of granite as a surface rock at the time the Huronian sediments formed is proved by the occurrence of belts of granite, conglomerate, and breccia in different horizons of the series.

A large belt of conglomerate, formed of rounded weather-worn granite pebbles and schistose rock fragments, cemented by a matrix of similar schistose material, is seen in contact with a granite belt in the south half of sec. 2, T. 48 N., R. 26 W.; in the SE. ¼ sec. 22, T. 47 N., R. 26 W.; and in the north half of sec. 29, T. 48 N., R. 25 W. In the first of these localities the fragments are different from the underlying granite. The second locality furnishes a better proof of the deposition of Huronian sediments on a base of granite. Here several knobs centrally composed of massive granite are surrounded by a mantle of coarse granite breccia, with a well-laminated quartzose material as a cement. This breccia is conformably succeeded by hydromica slates, interlaminated with heavy belts of compact quartzite. At the third locality granite conglomerate is interlaminated with dioritic schists, but is remote from granite outcrops. The gradation of the quartzite formation into the granite, described in the previous report as occurring in the north part of T. 47 N., R. 25 W., is now considered as a recemented mixture of granite fragments mingled with arenaceous material, although it is singular that the orthoclase crystals copiously found in the mass have all sharp outlines and are rather fresh.

The upheaval of the granite and its intrusion into the overlying strata occurred in all probability near the termination of the Huronian period, as we find the granite in contact with all the Huronian strata up to the youngest, and these always in a dislocated position. Intrusive belts of granite are usually never found to intersect beds higher than the Iron group, except in the country north of the Penokee range in Wisconsin and in the vicinity of Duluth, Minn., where granite or granite-like rocks cut across eruptive belts of gabbro which are themselves more recent than any of the sedimentary strata of the Huronian. These granites differ from the ordinary granites at the base of the Huronian, and are most likely younger. The dislocation of the Huronian beds is not exclusively due to the upheaval and intrusion of the granite, but has been caused in part by diorite and diabase intrusives which intersect the granite as well as the incumbent beds. The diorites intersecting the granite are identical with similar rocks interstratified with the schists of the Huronian group conformably or transversely intersecting them, and they therefore represent one and the same volcanic injection. From the massive forms of diorite a gradation exists into a schistose condition. This led to the conclusion in the former report that the massive diorites had suffered secondary fusion; but as the author is now convinced that schistose structure is not necessarily the result of aqueous sedimentation, it is concluded that the Dioritic group does not belong in the sedimentary succession. Dolerite or diabase rocks intersect in dikelike form all the Huronian rocks, as well as the granites. As they are like those of the copper-bearing series, these rocks, as well as the contemporaneous flows, are regarded as belonging to the same geological period. In the Felch Mountain region one dike (15 or 16 feet in thickness) of holocrystalline granite cuts across the iron-bearing series. In sec. 33, T. 42 N., R. 28 W., another granite dike cuts through the iron-bearing rocks.

Above the Iron group of the Marquette and Menominee districts, before described, are found at many localities in both these regions important deposits of iron which belong in the Arenaceous Slate group. There are, therefore, two iron horizons instead of one, as before supposed. The Mica schist formation, supposed to belong above the Arenaceous Slate group, is found to dip conformably below it in some places, and therefore is really a part of the Arenaceous Slate group, and is believed to represent its middle horizon. The slate group about L'Anse and Huron Bay is black and often graphitic.

The slate beds at Plumbago Brook are succeeded by schistose beds richer in red feldspar and containing little quartz, which might by superficial examination be mistaken for granite, but which is evidently a fragmental rock formed by the detritus of the granite, which near by forms large mountain masses, and the granite of which is very rich in red feldspar and contains comparatively little quartz.

The Gogebic region is described and the rocks are divided into granitic, dioritic, iron-ore, and upper slate groups, which are analogous to the similar groups in the Marquette country. Granite seams were found here cutting across the dioritic schists, but were not found to cut the truly sedimentary strata. Locally, in contiguity with the granite, are heavy quartzite strata which are often conglomeratic, and are filled with rounded granite pebbles. The dioritic rocks above the granite often have a brecciated or conglomeratic structure, the fragments being various kinds of diorite cemented by the same material. The diorite is of eruptive character, as is shown by the occurrence of belts of it cutting transversely through the ore-bearing series. Limestones are also found, which occupy the same position as the limestones below the ore-bearing strata in the Menominee district.

The succession in Felch Mountain, from the base upward, is (1) granitic or dioritic rocks, (2) quartzite beds, (3) fissile quartz schists, (4) micaceous argillite, (5) crystalline limestone with siliceous seams, (6) ferruginous quartzites, containing the ore beds.

Wadsworth,[45] in 1884, as a result of an examination of a supposed fossil from the copper-bearing rocks of Lake Superior, described by Hall as being very like the Huronia or siphuncles of *Orthoceratites*, finds it to be of inorganic origin, having probably been formed by the flowing of a pasty lava in such a manner as to raise a series of ridges, giving an appearance closely like that of some cephalopods. The interior of the specimens is in all respects like that of an ordinary volcanic rock.

Irving and Chamberlin,[46] in 1885, give a systematic account of the junction between the Eastern sandstone and the Keweenaw series on Keweenaw Point. Detailed descriptions are given of the relations of the two series at Bete Grise Bay, the Wall ravine, the St. Louis ravine, the Douglass Houghton ravine, Torch Lake quarry, the Hungarian ravine, and other points. The conclusions, and the grounds upon which they are based, of Jackson, Foster and Whitney, Agassiz, Rominger, Credner, and those who have followed them, are discussed in detail.

At Bete Grise Bay the horizontal sandstone is found upon approaching the melaphyre to become tilted upward, and along the junction is found the evidence of faulting, both in the fluccan of the sandstone and in the broken character of the melaphyre at the contact. At the Wall ravine the sandstone and conglomerate bearing fragments of the porphyry conglomerate, with which rock the contact here occurs, are found to dip at a considerable angle away from the eruptive rock and to rest directly upon it. At the St. Louis ravine the sandstone is found, upon approaching the Keweenaw series, to become rapidly tilted upward, and before reaching the Keweenawan rocks to become vertical, while the interstratified eruptives and detrital rocks of the Keweenaw series dip away from the sandstone. At the Douglass Houghton ravine the horizontal sandstone is found, upon approaching the Keweenaw series, to become bent into a series of folds and to dip downward under the traps and porphyries, which dip at a steeper angle in the same direction. Along the contact the trap is shattered. At the Torch Lake quarry the sandstone is found to be in a horizontal position, there being found no evidence whatever that this structure is jointing or that the real dip has an inclination, as described by Wadsworth. The crystal outlined grains of sand here contained are found to be produced by secondary growth rather than crystals derived from quartz porphyry. At the Hungarian ravine the relations are much the same as those at the Douglass Houghton ravine, except that the Keweenawan diabase is interstratified with conglomerate instead of quartz porphyry. Along the contact the sandstone is broken.

In getting at an explanation of the facts there must be taken into account the bedded nature of the Keweenaw series; the uniformity and steadiness of dip; the enormous thickness of the Keweenaw series; the general horizontality of the Eastern sandstone; the quartzose character of the Potsdam sands in distinction to the silicate nature of the Keweenawan sands; the mutual relations and distribution of the two series; the relations to topography; the relations of the two series to drainage; the comparative straightness, but with gentle undulations, of the junction line throughout its course of nearly 100 miles; the coincidence of the line of escarpment with the line of junction of the two series; the disturbance along the line of contact; the special character of the distortions; the character of the junction; the junction débris; the irregular and broken contact facies of the two series; the fact that the contact occurs between the Eastern sandstone and different members of the Keweenaw series; the discordance of strike; the derivation of the pebbles of the Eastern sandstone from the Keweenaw series; the distribution of the pebbles, those of the Keweenaw series being found only near the immediate junction; the imperfect assortment of the pebbles and matrix near the junction; the angularity of the pebbles at this place; the absence of large fallen masses of trap in the Eastern sandstone; and the proximity and relations of the Trenton limestone, resting as it does upon the Eastern sandstone within a short distance. These specifications are taken to point with distinctness to the conclusion that the Keweenaw series is much older than the Eastern Potsdam sandstone; that it was upturned, faulted along the escarpment, and much eroded before the deposition of the Eastern sandstone; that the latter was laid down unconformably against and upon the former, and that subsequent minor faulting along the old line ensued, disturbing the contact edge of the sandstone.

Fulton,[47] in 1888, describes the Huronian rocks of the eastern Menominee region as consisting of three formations. The basal formation is a crystalline siliceous limestone at least 1,200 feet thick, which outcrops at many localities along the range, especially north of the Norway, Quinnesec, and Chapin mines. The next group, estimated at a thousand feet in thickness, is the Quinnesec ore formation. It consists of siliceous or jasper slates, largely impregnated with iron oxides. These are succeeded by argillaceous hydromica slates and flesh-colored slates. This formation embraces the deposits of iron ore. The third formation is a series of dark-gray, slaty, or schistose rocks, with occasional quartzose bands, having a thickness of 2,000 feet, and is called the Lake Hanbury slate group. Detailed sections at the East Vulcan, Curry, Norway, Cyclops, and Quinnesec mines are described. In some cases the ore is associated with the Potsdam sandstone, which rests unconformably in a horizontal position upon the flexed and denuded Huronian rocks. The iron-ore beds in the Huronian are generally associated with aluminous slates or soapstones.

Winchell (N. H.),[48] in 1888, describes the conglomerate overlying the ore and jasper formation at several mines in the Marquette district, and places the overlying quartzite in the Potsdam. North of Bessemer is a basal conglomerate of the cupriferous series which is inferred to lie unconformably upon the Gogebic iron-bearing rock. This conglomerate appears to be the equivalent of the overlying Potsdam conglomerate of the Marquette region, which makes the Gogebic series pre-Potsdam. The granite underlying the Huronian slates at the Aurora mine was originally a conglomerate, but it has acted the rôle of an eruptive rock and has flowed over the adjoining sedimentary strata. This granitic conglomerate is parallelized with the Ogishki conglomerate of Minnesota, and the overlying sedimentary rocks are the equivalent of the Animikie.

Winchell (Alexander),[49] in 1888, finds the Marquette iron-bearing rocks to have the same geological position with respect to the crystalline schists and gneisses, and to consist of sediments of the same character, as those of the Vermilion range. At Deer Lake furnace is a peculiar conglomeratic rock which appears to be sedimentary, but is much altered and has a quasi-eruptive aspect. This conglomerate is like that of Stuntz Island, in Vermilion Lake. Near Negaunee is an argillite which has a lower dip than a greenish chloritic quartzose rock across a railroad from it, and the two are therefore unconformable.

The rocks of Marquette are older than the Huronian, because they differ from them lithologically; because the Canadian Huronian is immediately succeeded by the Paleozoic system, while the Marquette strata are not; because some evidences are found that in the Marquette district there is an overlying unconformable sub-Paleozoic system, and because the Marquette series, being the equivalent of the Vermilion, is older than the Animikie slates, which are the equivalent of the Huronian.

The rocks of the Gogebic range are regarded as the equivalent of those of the Marquette region because they resemble them lithologically and because they are in an analogous position to the crystalline rocks. Between the Penokee series and the underlying schists there is a marked unconformity, the Penokee rocks dipping to the north, while the hornblende schists dip to the south. The Penokee series strata are lithologically unlike the ore-bearing strata of the Gogebic, Marquette, and Vermilion regions, but resemble those of the Animikie series and are therefore perhaps Huronian, while the Gogebic iron-bearing strata are not.

MERRIAM,[50] in 1888 and 1889, in a detailed systematic study of parts of the Marquette district, ascertained that about many of the masses of basic eruptives the clastic rocks bow in a quaquaversal manner, indicating that many of the diabases, gabbros, and diorites are intrusive subsequent to the formation of the Marquette series, and that the local strikes and dips are often due to this cause.

VAN HISE,[51] in 1890, examined the rock succession at Iron Mountain, Michigan. Overlying the ore formation of the Ludington and Chapin mines is a conglomerate which bears fragments of ore and jasper. It therefore appears that after this material reached its present condition in the ore-bearing series it was eroded and furnished débris for a newer series.

WILLIAMS,[52] in 1890, as a result of an extended examination of the field relations and microscopical characters of the widespread greenstones, greenstone schists, and agglomerates of the Marquette and Menominee districts, concludes that they are all of eruptive origin. This conclusion is reached from a consideration of the field evidence, the schistose phases being frequently traced by continuous gradations into massive forms, and of the microscopical evidence, these unaltered forms having all the characteristics of eruptive rocks. The original rock types were rather numerous, including gabbro, diabase, diabase porphyry, melaphyre, diorite, diorite porphyry, and tuffs. These rocks have been compressed, faulted, and crushed, as a result of which, combined with metasomatic changes, their present condition is produced.

Wadsworth,[53] in 1890, gives a general account of the geology of the Marquette and Keweenaw districts based upon his own and other works. The Azoic system includes fragmental and eruptive rocks. Among the former are various argillites and schists of the Marquette district. Among the eruptive rocks are placed the jaspilites and their associated ores, with the exception of certain soft iron ores of chemical origin. The Keweenawan is again placed as a part of the Potsdam, since the first lava flow found on Keweenaw Point flowed over the Eastern sandstone. Subsequently there has been a fault line or fissure running near the contact of the sandstones and lavas. This fault is regarded as normal, and it accounts for the fact that sometimes the lavas and sometimes the associated conglomerates are brought in contact with the Eastern sandstone along the fault line.

Irving,[54] in 1890, discusses the field relations of the greenstones and greenstone schists of the Marquette and Menominee districts. A field study of these rocks, heretofore generally considered sedimentary, led to the conclusion that they are largely of eruptive origin, and the detailed study of Williams has shown this conclusively. In the Marquette district the line of demarcation between the schists and the granites is not a sharp one, the granites intricately intruding the schists, often in such a manner as to render it certain that the granite is the later rock. Also the basic dikes which cut the greenstone schists are of wholly subsequent date to the schists themselves, and are equivalent in age to those which have intruded the overlying detrital iron-bearing series. On the other hand, it is concluded that the greenstone schists themselves do not belong within the same geological period as that which holds the remainder of the stratiform rocks of the region; that is, the greenstone schists are placed along with the granites and gneisses to form the basement upon which the overlying detrital iron-bearing series was horizontally and unconformably spread. This is shown by the fact that at a number of points the detrital beds which form the basement member of the iron-bearing series proper bear numerous waterworn fragments of the granite when in contact with that rock, and fragments of the greenstone schists when in contact with those rocks. In some cases the basal quartzite appears to grade into the granite, but a study of this quartzite in the thin section shows its completely fragmental character. These contacts or basal conglomerates are described in secs. 1, 2, 3, 4, 5, T. 47 N., R. 25 W.; in secs. 21 and 22, T. 47 N., R. 26 W.; in sec. 29, T. 48 N., R. 25 W.; in sec. 20, T. 48 N., R. 27 W.; in sec. 17, T. 48 N., R. 26 W.; in sec. 21, T. 48 N., R. 27 W.; and at various points in T. 49 N., R. 28 W., all in Michigan.

From these occurrences it does not appear possible to escape the conclusion that the greenstone schists, together with the granite, are greatly older than the detrital rocks, and before the latter were formed had already suffered disturbance and deep denudation. This is certainly true if the underlying rocks are fragmental, and the conclusion can not be escaped if they are eruptive, for both the greenstone schists and the gneissoid granite must have received their schistosity before yielding the fragments; and, moreover, their character is such that it is generally believed that they must have crystallized in depth, and must therefore have had removed from them great masses of material before yielding the discovered fragments to wave action. There are evidently granitic rocks of two ages in the Marquette district, because dikes of a fine-grained reddish granite frequently cut the other granite. This later granite, of relatively small extent compared with the main masses, may perhaps have been later in time of formation than the detrital rocks themselves, as indicated by the presence of rare quartz porphyry dikes and rare granitic dikes in the Felch Mountain district intersecting a ferruginous schist of the iron-bearing series.

The above conclusions are further confirmed by the fact that the later greenstones interstratified with sedimentary layers, as shown by Williams, are precisely like the corresponding dikes in the greenstone schist area, which were evidently intruded subsequent to the production of a schistosity. Also the schistosity of the greenstone schists corresponds at times with the bedded structure of the iron series, while at other times there is no such correspondence. A similar examination of the facts in the Menominee district leads to identical conclusions; that is, that the granite both south and north of the iron-bearing series and the associated green schists and gneisses constitute a complex upon which the newer series was deposited.

Irving and Van Hise,[55] in 1890 and 1892, give a detailed description of the Penokee series of Michigan and Wisconsin, of the complex of rocks south of this series, and discuss the relations which the Penokee rocks bear to the underlying and overlying series, as well as to the Eastern sandstone.

South of the Penokee series is the Southern Complex, an area of fine-grained green hornblende schists and mica schists, gneisses, and granites. There is often no proper contact between the granite, gneiss, and schist, but an apparent gradation through a considerable distance from one to the other, while the granite often also cuts the schist, playing the part of a later intrusive. Distant from the lines of contact the schists occupy considerable areas. In none of these rocks is discovered any evidence of clastic origin. If the massive granites and syenites are regarded as eruptive, it must be concluded that many of the schists also have a like origin, because of the gradations between them.

The Penokee series proper is made up of three members, Quartz slate, Iron group, and Upper slate, and these rest unconformably upon a Cherty limestone member.

The Cherty limestone below the base of the Penokee series proper varies in thickness from nothing to 300 feet and is not continuous. This member as a whole shows no evidence of mechanical origin, although occasionally a small amount of detrital material is found in it. It is regarded as either a chemical or an organic sediment, and is called the Lower Penokee formation.

The Quartz slate member, resting upon the Cherty limestone or upon the Southern Complex, is a continuous persistent layer of very constant thickness for many miles. It is for the most part in the neighborhood of 450 feet thick, although at one locality it reached 800 feet in thickness. The rocks of which it is composed comprise feldspathic quartz slates, biotitic and chloritic quartz slates, and vitreous quartzite, the latter being a persistent phase at the uppermost horizon. All these rocks are plainly fragmental and for the most part little altered, although occasionally by metasomatic changes they have become semicrystalline. The lowest horizon of the Quartz slate in the Penokee series proper was found at times to be a vitreous quartzite and at other times to be a conglomerate. The débris of this conglomerate is usually derived chiefly from the Southern Complex, but at several localities contains a large quantity of chert from the Cherty limestone member, and also includes a considerable amount of red jasper pebbles, and occasionally contains pebbles of white vitreous quartzite.

The next overlying formation is the Iron-bearing member, which is longitudinally coextensive with the underlying Quartz slate. The thickness of this formation is surprisingly uniform, varying for the most part between 800 and 1,000 feet, although at its eastern extremity it apparently becomes thicker. The main phases of rocks here included are slaty and cherty iron carbonates, ferruginous slates and cherts, and actinolitic and magnetitic slates, none of which show any evidence of being of mechanical origin. The original form of the entire formation is taken to be an impure cherty iron carbonate, also bearing magnesium and calcium carbonate. From this condition the many phases and varieties of rocks now found are traced by minute stages. These transformations are mainly produced by secondary chemical changes. A comparison with the iron-bearing formation of the Animikie shows that it consists of the same kinds of rocks, which have been derived from an iron carbonate in the same manner as those of the iron formation of the Penokee series. The iron ores are found to rest for the most part upon the underlying quartzite and upon a series of dikes which have cut the stratified layers. The ores in this position are secondary concentrations regarded as produced at the same time as the modifications of the Iron-bearing member and due to downward-percolating water, which has removed silica and has substituted iron oxide.

The Upper slate member follows above the Iron-bearing member. It is of great and variable thickness, the maximum being more than 12,000 feet, and it varies from this to entire disappearance, the overlying series coming in contact with the Iron-bearing or lower members. The rocks here comprised are mica schists and mica slates, graywackes and graywacke slates, clay slates or phyllites, and quartzites and conglomerates, all of which are of original mechanical detrital origin. The mica schists and mica slates are traced by imperceptible stages back to their original little altered or unaltered condition.

These three members constitute the Penokee series proper. The eastern area of the series is found to differ in many respects from the main area already described. This was the center of great contemporaneous volcanic activity, and consequently the succession includes large thicknesses of lava flows and volcanic tuffs, which are not paralleled by the rocks found in the western area, and as a result of this disturbing force the detrital succession is not so simple and regular.

With the Penokee series are found eruptives of two classes—dikes cutting the formation and interbedded sheets, which are probably intrusions of the same age as the dikes. These eruptives are usually diabases, which are, like the dikes, found in the complex below the Penokee series, and which chemically are like the overlying Keweenaw series.

The Penokee series has approximately an east-west strike, is unfolded, and dips to the north at an angle varying usually from 60° to 80°. There are sharp flexures at a few points and small faults at only two localities.

While the strikes and dips of the Penokee series are persistent, those of the underlying schists are variable and often are at marked discordance with the Penokee succession. The granites which cut the fine-grained schists of the underlying complex are never seen to intersect the limestone or quartz slate. At a number of places the limestone or quartz slate is found immediately adjacent to or in actual contact with the underlying complex, when it is always found to bear numerous waterworn fragments from the Southern Complex, the condition of which is that of the rock from which it is derived. When the contact is with the green schists the schistose structure of the underlying rocks abuts against the strike of the quartz slate, while the fragments, with their greater length parallel to the schistose structure, are found with their longer diameters in the direction of the bedding of the slate, showing that their schistosity was produced before they were broken from their original position. It is then concluded that the Southern Complex is separated from the Penokee series by a great unconformity, and that, as the quartz slate is persistent for a distance of many miles, the underlying complex had nearly reached a base-level before the overlying series was deposited.

Above the Penokee series are the Keweenawan rocks, which at Tylers Fork are found above a thickness of at least 13,000 feet of sediments belonging to the Penokee series. In passing east or west from this point the Keweenawan rocks come in contact with lower and lower horizons of the Penokee series. At one place the entire succession appears to be cut off by it. This is taken to imply that between the deposition of the Penokee series and the outflows of Keweenawan time a sufficient time elapsed for erosion to remove at least this thickness of sediments, and consequently that between the Keweenawan and the Penokee series there is a very considerable unconformity.

This unconformity is not, however, evident in single cross sections. The bedded Keweenawan traps have a high inclination which is not markedly different from that of the Penokee succession. The inclination of this bedding is ascertained by the contacts of the different flows, by the inclination of their amygdaloidal horizons, and, north of Bessemer, by the contact between the traps and an interleaved sandstone.

At Lake Gogebic the Eastern sandstone is found to rest, in a horizontal position, against the upturned edges of the Southern Complex and Penokee series alike, and to contain numerous characteristic fragments which can have been derived only from these series. Also very numerous fragments equally characteristic of the Keweenaw series are found, and it is therefore concluded that after the deposition of the Penokee and Keweenawan series, before the Eastern sandstone was laid down, the two former were upturned and suffered great denudation.

A comparison of the Penokee series proper and the Animikie series shows that they are made up of a like succession of rocks, occupying the same relative positions with reference to overlying and underlying rocks, one dipping northward under the basin of Lake Superior and the other dipping southward under the same body of water. They are therefore regarded as equivalent. As probably equivalent with the Penokee series are also placed the various areas of rocks in the Lake Superior basin referred to the Upper Huronian.

A comparison of the Penokee with the Marquette succession shows that there is a very close correspondence. Unconformably below the

Marquette and Penokee clastics is a crystalline basement complex. Within the pre-Keweenawan clastics in each district is a second physical break. Below this break, in the Penokee district, the formations of the Lower Marquette are now represented only by the Cherty limestone. That other members once existed is indicated by the presence of fragments of jasper and quartzite in the lowest horizon of the Quartz slate. Formations composed of these rocks and a cherty limestone are the characteristic members of the Lower Marquette.

The correspondence of the members of the Penokee series proper with those of the Upper Marquette is complete. The Upper Marquette and Penokee series, looked at broadly, are great slate formations, both of which contain, near the base, an iron-bearing horizon. In the Penokee series that portion of the slate overlying the ore formation has been called the Upper slate member, and that below it the Quartz slate member. The lower part of the Quartz slate is a quartzite and conglomerate, which corresponds to the quartzite and conglomerate forming the base of the Upper Marquette series. The uppermost horizon of the Penokee Quartz slate is a narrow layer of persistent quartzite, which does not appear to be represented in the Marquette district. The ore-bearing member is identical in character in both districts, being unquestionably derived from a lean, cherty carbonate of iron. The characteristic rocks of both are now the iron carbonates, ores, and cherts containing bands and shots of ore. The chief difference between the two is that in the Penokee district the actinolite-magnetite schists are more prevalent and the iron-bearing formation is more persistent. Connected with this fact is perhaps the presence of the upper horizon of quartzite, which shows that a clearing up of the waters occurred before the beginning of deposition of the iron-bearing sediments. A still further analogy between the Penokee and the Upper Marquette series is the presence in both of abundant surface volcanics. We have then in the two districts the following parallel descending pre-Keweenawan succession:

PENOKEE.	MARQUETTE.
Upper slate, locally mica schist.	Upper slate, rather extensively mica schist.
Iron-bearing formation.	Iron-bearing formation.
Quartz slate; upper horizon persistent quartzite; central mass a slate; lower part often conglomeratic, bearing fragments of lower series, and locally a quartzite.	Lower slate; lower part quartzite or quartzite conglomerate, bearing fragments of lower series, either Lower Marquette or Archean.
Unconformity.	Unconformity.
Eroded away.	Iron-bearing formation.
Limestone.	Limestone and lower quartzite.
Unconformity.	Unconformity.
Basement complex.	Basement complex.

WADSWORTH,[56] in 1891, modifies somewhat the account of the Azoic system given by him in 1890.[53] A portion of the jaspilites and associated iron ores are still held to be eruptive, but it is suggested that the present relations of even these supposed nonfragmental jaspilites of Ishpeming and Negaunee may be due to sedimentary and chemical action and the squeezing together of the jaspilite and schist. The jaspilite and ore, with the associated quartzites, occurring at Cascade, Republic, Humboldt, and a part of those at Ishpeming and Negaunee, as well as those of the overlying quartzites and schists, are sedimentary. In the Marquette district there are three distinct geological formations or ages, in ascending order as follows: First, the hornblende schist and granite of Cascade or Palmer and the nonfragmental jaspilite and ore of Ishpeming and Negaunee—the Cascade formation. Second, the fragmental jaspilite and ore, with their associated quartzites and schists, of Cascade, Republic, Humboldt, Ishpeming, Negaunee, and elsewhere—the Republic formation. Third, the overlying conglomerates, quartzites, and schists of Cascade, Republic, Holyoke, and elsewhere—the Holyoke formation.

Above the detrital Republic formation at the Cascade range is another detrital formation which contains waterworn débris derived from the underlying deposits of jaspilite and ore, and is therefore uncomformably above it. At present it is not possible to determine positively whether there are really three formations as given, or from four to six different ones, or whether the three may be reduced to two.

WADSWORTH,[57] in 1891, finds that the Lower Silurian, containing Trenton fossils near L'Anse, overlies the sandstone conformably, both having a synclinal structure; which tends to confirm the commonly received view of the Potsdam age of the Eastern sandstone.

WADSWORTH,[58] in 1891, gives observations upon the south trap range and adjacent sandstones. Various places are mentioned, including Silver Mountain, which are composed of lava flows. These traps sometimes have a dip not higher than 9° to 20°. In secs. 11, 13, and 14, T. 46 N., R. 31 W., sandstone is found overlying the lava flows. The Eastern sandstone on Traverse Island, in Keweenaw Bay, is said to have an inclination of 5° to 14°, while in the vicinity of Torch Lake it has a dip of 5° to 23°. It is concluded that the above observations go to show that the lava flows of the south trap range east of Lake Gogebic do not dip at a high angle, as has been generally asserted, and further that the Eastern sandstone is not horizontal, as has been generally stated, but that the two dip at a low angle, generally 5° to 20°. These observations also indicate that the Eastern sandstone and the lava flows of the south trap range are one formation, and are as conformable as eruptions of lava can be with a contemporaneous sedimentary deposit.

PUMPELLY and VAN HISE,[59] in 1891 and 1892, find that in places the ore formation of the Menominee and Felch Mountain districts passes down into the limestone. In the deeper workings of the Chapin the ores resting almost directly upon the limestone are found to bear a considerable percentage of carbonates, including iron, calcium, and magnesium. The Metropolitan ore deposits in the Felch Mountain district are found associated with or within the limestone. At one pit the ore and jasper may be seen interlaminated with and grading down into a limestone. It is therefore probable that the ore formation of these districts, in part at least, is but an upward continuation of the limestone formation, perhaps differing from it originally only in that the upper part contained a greater quantity of original carbonate of iron.

Above the ore formation at Quinnesec test pits show the presence of a typical chert and jasper conglomerate, in every respect like the basement conglomerates of the Upper Marquette.

VAN HISE,[60] in 1892, describes the Huronian volcanics south of Lake Superior. These include both lavas and tuffs interstratified with each other and with contemporaneous clastics. Among the lavas are amygdaloids, the amygdules of which are in certain cases jasper similar to that of the iron formation adjacent, and are believed to have been formed at the same jasper-forming period. The volcanics are much more altered than those of the Keweenawan. They are found in various places, but the most extensive areas are in the Gogebic district west of Gogebic Lake and in the Michigamme district north of Crystal Falls. In the first locality the series is 7,000 or 8,000 feet in thickness. This great mass of material was piled up while to the west 700 to 800 feet of the sediments of the iron-bearing formation were accumulating. In this district, therefore, at the same time there were being deposited the ordinary sediments of the area and locally a volcanic series of a wholly different character.

LANE,[61] in 1892, holds that certain of the ore bodies of the Marquette district are produced by abstracting iron oxide from amphibolites and depositing this material at other places. The water is regarded as upward moving, hence the ore bodies rest upon the diorites as foot walls. It is not denied that in other places the iron is derived from a carbonate, or that silica is replaced by the iron oxide. At the Volunteer mine the ore seems in part to have replaced the sandstone.

WADSWORTH,[62] in 1893, gives a sketch of the iron, gold, and copper districts of Michigan. The Azoic or Archean rocks are divided from the base upward into the Cascade, Republic, and Holyoke formations. These divisions are placed in order as equivalent to the fundamental complex, Lower Marquette series, and Upper Marquette series of Van Hise. They are unconformable and represent three different geological ages. The Keweenawan is divided into two divisions, both of which are placed in the Cambrian—the Lower Keweenawan, 25,000 feet of interbedded conglomerates and lava flows, with some intrusives; the Upper Keweenawan, 12,000 feet of sandstones and shales, not separable from the Potsdam or Eastern sandstone.

The Azoic or Archean system consists of rocks formed (1) by mechanical means, (2) by eruptive agencies, (3) by chemical action.

The Cascade or oldest formation of sedimentary and eruptive rocks consists, commencing with the oldest, of gneissoid granites or gneiss, basic eruptives and schists, jaspilites and associated iron ores, and granites, although the above arrangement may be considered no more than a hypothesis, and it is probable that the jaspilites and iron ores will be found to belong to the Republic formation. It is also probable that the Cascade formation itself will prove to be composed of two or more distinct geological formations, as shown by the fact that the chief rock of the Huron Mountains appears to be a gneissoid granite, rather than a true sedimentary gneiss. True sedimentary gneisses are found in the Huron Bay and Cascade districts. In the former area they contain fragments that closely resemble the gneissoid granites, and thus they appear to be formed from the débris of those rocks. If, however, the gneissoid granites are metamorphosed eruptive rocks, and not true gneisses (which are restricted to metamorphosed sedimentary rocks), this fact proves only that the gneisses are younger in order of time, but not necessarily of younger geological age. Similar statements apply to the breaks between the Cascade and Republic formations, and the break between the Republic and Holyoke formations. In the Huron Bay, Menominee, and other districts the Cascade formation holds intrusive granites. Amphibole schists are also found intrusive in the gneisses in the Cascade area. In the Marquette area the amphibole schists are cut by felsite or quartz porphyry.

Much of the granite and felsite appears to have been erupted during the time of the Cascade formation, and perhaps even later. On the Cascade range hornblende gneiss cuts the country rock. These dikes are cut by other dikes containing crystals of feldspar, while both are cut by gray granite that is in turn cut by red granite.

The Republic formation, commencing with the oldest division, is divided roughly as follows: Conglomerate-breccia and conglomerate schist; quartzite; dolomite; jaspilite and iron ore; argillite and schist; granite and felsite; diabase; diorite and porodite; porphyrite. At the base of the Republic formation is a series of conglomerates and conglomerate schists, which pass into hydrous mica schists. Near Palmer the coarse conglomerate rests on the gneiss to the south, and is overlain to the north by quartzite, fragmental jaspilite, and quartz schist. The dip is about 40° N. The conglomerate contains numerous pebbles of gneiss, as well as some of granite, diorite, schist, and quartz veins. Near the Volunteer mine quartzite immediately overlies the basal conglomerate, and in other places reposes directly on the Cascade formation.

The quartzite in the Menominee district, running from Sturgeon River along Pine River to Metropolitan, is thought to belong to the base of the Republic formation, since it is found at various places close to the gneiss and granite, dipping away from them, and is cut by dikes of granite in sec. 12, T. 41 N., R. 30 W. The dolomite occupies a low horizon, either interbedded with the quartzite or occupying its place. The fundamental ore and jaspilite appear to belong, stratigraphically, to the Republic formation. Most of the jaspilite of the formation is of detrital origin, being originally conglomerates, breccias, sands, and muds, which have been subsequently chemically acted upon by percolating waters, since in the Cascade range the jaspilite and ore form layers which are frequently interlaminated with quartzite. The jaspilite of Negaunee and Ishpeming has failed to reveal any evidence that it is sedimentary, although the associated argillite and schist are, in part at least, clearly sedimentary. The argillite and schists are directly associated with the jaspilite and iron ore. In places they grade up into the fragmental jaspilite, and in other places are interbedded with it. They also succeed the latter rocks and overlie them. These argillites and schists are older than the diorites of the district, and are cut by them.

The Holyoke formation has the following succession, as far as known, commencing with the base: Conglomerate-breccia and conglomerate schist; quartzite; dolomite; argillite; graywacke and schist; granite and felsite; diabase, diorite, and porodite; peridotite, serpentine, and dolomite; melaphyre or picrite; diabase and melaphyre. The conglomerate at the base of the Holyoke contains granitic material, as well as fragments from the jaspilite. In many places the unconformity between the Republic and Holyoke formations is most marked, being seen at many of the mines. In many places, also, the Holyoke formation overlaps the Republic and is in contact with the granite and gneiss of the Cascade. Associated with the Holyoke conglomerate is a quartzite which includes the Mount Mesnard and Teal Lake quartzites. In sec. 20, T. 47 N., R. 26 W., and secs. 8 and 19, T. 49 N., R. 28 W., near Silver Lake and in other places, sediments of the Holyoke formation have sifted down into the fissures and joints of the preexisting rocks, when they have a dikelike character. For such formations the term "clasolite" is proposed. The dolomite of Mount Mesnard and thence to Goose Lake, while lithologically like that placed in the Republic formation, is doubtfully referred to the Holyoke. Argillite, graywacke, and mica schist occur extensively in the Holyoke, constituting the upper horizon. It is doubtful whether any granite or felsite of Holyoke age exists in the Marquette district.

Diabase, diorite, porodite, and peridotite occur abundantly, belonging to both the Republic and the Holyoke formations. According to

Seaman diabase dikes of the Gogebic area are probably the same as those that cut the overlying sandstones of the Keweenawan, from which it is concluded that the Keweenawan lava flows are the effusive equivalents of the Holyoke diabase dikes.

The soft hematites of the region are produced by secondary enrichment at places where the water could best act, being at points of fracturing or in basins. The silica of the lean material has been leached out and iron oxide substituted. Gold and silver veins are discussed and a classification of ore deposits is given.

The Eastern or Potsdam sandstone rests unconformably on the Azoic. This includes the unaltered horizontal sandstone, which is free from dikes of eruptive material, and the Keweenawan, which consists of lava flows alternating with sandstones and conglomerates, largely derived from the former. Above, and conformably with the Eastern sandstone, near L'Anse, is limestone of Silurian age, as shown by its fossil contents. On Keweenaw Point the Eastern standstone dips toward, and passes under, the interstratified sandstones and lavas of the Keweenawan. At or near the contact is a fault. However, at Douglass Houghton and Hungarian rivers it is thought not to be at the contact, and consequently that the Eastern sandstone underlies the Keweenawan lava, but the Eastern sandstone may contain two or more sandstones of different ages, which may perhaps be considered as the most probable explanation of all the evidence. In sec. 13, T. 46 N., R. 41 W., on the south trap range, a nearly horizontal, soft, friable micaceous sandstone is found near the interbedded Keweenawan melaphyre and indurated sandstone. This soft sandstone contains numerous spherical spots very common in the Eastern sandstone, but not found in the Keweenawan. In the soft sandstone are found pebbles and large angular fragments of indurated sandstone, which Seaman thinks could have been derived only from the adjacent indurated sandstone. The rocks of the trap range here exposed are believed by Seaman to hold a position near the top of the Keweenawan series, and he concluded that the soft sandstone belongs to a distinct and later geological age than the trap range.

The character and origin of the copper deposits are discussed.

Wadsworth,[63] in 1893, states that recent work renders it probable that the Azoic or Archean of northern Michigan is divisible into five unconformable formations. The tentative arrangement, commencing with the oldest, with the parallel formations as determined by the United States Geological Survey, is as follows:

Michigan Geological Survey.	United States Geological Survey.
Cascade formation	Fundamental Complex.
Republic formation Mesnard formation	Lower Marquette series.
Holyoke formation Negaunee formation	Upper Marquette series.

VAN HISE,[64] in 1893, gives the following as the ascending succession in the iron-producing part of the Marquette district: (1) Basement Complex, consisting of granites, gneisses, schists, and greenstone conglomerates, the whole intricately intermingled, and the schists intruded by the granites and gneissoid granites; unconformity; (2) Lower Marquette series, having at its base a conglomerate and quartzite formation, upon which rests an iron-bearing formation; unconformity; (3) Upper Marquette series, which looked at broadly is a great shale, mica slate, and mica schist formation, but it often has at its base quartzites and conglomerates, and several hundred or a thousand feet from its base an iron-bearing formation similar to that of the Lower Marquette series. Included within both the Lower and the Upper Marquette series are many basic intrusive dikes and bosses of diabase, and also contemporaneous volcanics, which are largely tuffaceous.

At the east end of the Marquette district is the Mesnard series, the position of which has not yet been determined.

HULST,[65] in 1893, gives a résumé of the general geology of the Menominee district as explained by Brooks, and detailed sections of several of the mines. The descending succession at the Millie ore body and Chapin mine is as follows:

	Feet.
Quartzite; Jasper; Quartzite; Quartzite and jasper; Quartzite, slate, and jasper; Slate; Quartzite and slate; Quartzite and jasper	140
Banded ore, containing Millie ore body	300
Quartzite and slate; Slate	55
Jasper	170
Ore body.	
Gray slate	75
Ore; Gray slate; Jasper; Gray slate; Jasper G; Gray slate; Jasper; Ore; Gray slate	185
Limestone.	

The descending succession in the Pewabic mine is as follows:

	Feet.
Jasper and ore, containing Pewabic ore body	215
Gray slates	112
Quartz.	
Gray slate.	
Quartzite	77
Quartz and slate.	
Slate conglomerate	50
Red slate	77
Quartz and gray slate.	
Quartzite.	
Quartz and sand.	
Slate conglomerate.	
Quartz conglomerate	116
Red slate.	
Jasper.	
Red, gray slate.	
Limestone.	

The ore bodies are found in beds of banded lean jasper, which is always an invariable associate of the richer ore, and it may occur anywhere within the jaspery horizon. The rich ore often appears to be a part and parcel of the general stratification of the lean ore encompassing it. Not infrequently one finds spots which are apparently in the transition state from the lean jaspery ore, as though the ore body was charged with a solution which was gradually dissolving out the silica from the adjacent jasper. There is invariably a notable pitch to the ore bodies, and it is generally to the west at an angle of 30° to 50°. Connected with some of the ore bodies are well-defined hanging or foot walls of so-called soapstone, but often when there are no well-defined walls, the ore body being found in the jasper, the ore carries a minimum of phosphorus, as exemplified at the Millie, Pewabic, Cyclops, Aragon, and S. E. Vulcan mines. The productive portions of the range appear to be located at the points where the formation has been faulted, eroded deeply, or sharply folded.

Smyth,[66] in 1893, describes a contact between the lower quartzite of the Lower Huronian and the underlying granite at Republic, Mich. Below the lowest exposures of magnetite-actinolite schist are exposures of the lower quartzite, and below this, hanging upon the northern flank of the granite, is a conglomerate containing very numerous well-rounded bowlders of granite and gneiss, identical with the rocks immediately below. It is concluded that this conglomerate, from its position, can not possibly belong to the Upper Huronian, and that it is a true basal conglomerate of the Lower Huronian.

Hubbard,[67] in 1894, gives two geological cross sections of the Keweenawan series in the vicinity of the Calumet and Hecla and the

Tamarack mines. The strata here consist of interstratified traps, amygdaloids, sandstones, and conglomerates. Deep in the series there is less amygdaloid, and it is suggested that the amygdaloids are largely pseudo-amygdaloidal, their development being dependent upon subsurface weathering. It is found that the conglomerates approach each other in passing from the north toward the south, due to the thinning of the igneous beds. The Eastern sandstone, somewhat remote from the line of junction with the Keweenawan series, has at places a dip toward the traps as high as 10° or 12°. At Lake Linden this formation is shown by boring to be at least 1,500 feet thick, and to consist of red sandstone with several streaks of marl. The likeness of this sandstone to the Upper Keweenawan sandstone, the faulting along or near the contact line of the two formations, and the thinning of the traps and amygdaloids in passing toward the Eastern sandstone, seem to strongly favor the theory that the two formations are of the same age.

VAN HISE,[68] in 1894, describes the rocks of the Marquette district as constituting a great synclinorium. The axial planes of the minor folds on the sides dip toward the center of the synclinorium, thus resembling the fan structure of the Alps; but there is the great difference that the major fold is a synclinorium rather than an anticlinorium. This kind of fold may be called the Marquette type.

SMYTH (H. L.),[69] in 1894, compares the Lower Menominee and Lower Marquette series in Michigan. The Lower Menominee series consists, in ascending order, of—

1. A basal quartzite, rarely conglomeratic, having a thickness of 700 to 1,000 feet.
2. A crystalline limestone, averaging 700 to 1,000 feet in thickness.
3. Red, black, and green slates, not known to exceed 200 or 300 feet in thickness, and containing the iron formation that gives the rich ores of Iron Mountain and Norway. Toward the north the horizon of the slates is in part occupied by later eruptives that rapidly increase in thickness and attain a maximum of nearly 2,000 feet.
4. The Michigamme Mountain jasper. The least modified phase seems to be, in part at least, a sediment. The most highly altered kind is like the banded, specular jasper of Republic.

The Lower Marquette series in the western part of the Marquette area consists, in ascending order, of—

1. A basal conglomerate, quartzite, and quartz schist, probably less than 100 feet.
2. An iron-bearing formation, which may be divided into a lower actinolitic schist and an upper banded red jasper and specular hematite. This member has a maximum thickness of more than 1,000 feet.

The magnetic jasper of Michigamme Mountain has been traced, by means of outcrops and magnetic work, within 1½ to 2 miles of the iron-bearing formation of the Marquette series, and the two are regarded as equivalent. If this be true, the Lower Marquette quartzite may represent the lower quartzitic portion of the Michigamme jasper formation, in which case the whole of the Lower Marquette series would be represented by the highest member of the Lower Menominee.

The absence in the Marquette district of the equivalent of the great thickness of limestone, quartzite, and eruptives below the Michigamme jasper in the Menominee district is accounted for by supposing that the Marquette area was more elevated, and that the transgression of the ocean from the south reached the Marquette district when the lower portion of the Michigamme jasper was being deposited. If the above correlation be correct it further follows that the principal ore formation of the Menominee has no equivalent in the Marquette district.

The Mount Mesnard series of quartzite, limestone, and slates, as described by Wadsworth, in the eastern part of the Marquette area, between the Cascade range and Lake Superior, has many points of resemblance to that part of the Lower Menominee series below the Michigamme jasper. The age of the Mount Mesnard series is still in doubt, but if it should prove to underlie the Lower Marquette (Wadsworth's Republic formation) its position would probably indicate the limit of the old Marquette highland on the eastern side.

Smyth (H. L.),[70] in 1894, describes a quartzite tongue in the jasper at Republic. This tongue branches from the main mass of quartzite, and, after continuing nearly parallel with it for a long distance, tapers to a point toward the north in a mass of specular jasper. The quartzite tongue includes between itself and the main quartzite a similar jasper tongue, which starts in the north from the jasper and tapers to a point toward the south in the quartzite, the two tongues interlocking. These unusual relations are explained as due to faulting approximately parallel to the fold which occurred during the folding of the series.

Hubbard,[71] in 1895, describes the relation of the copper vein at the Central mine, Keweenaw Point, to the Kearsarge conglomerate. The veins of Keweenaw Point belong largely to one system, and are confined principally between T. 57 N., R. 32 W., and the northeast extremity of the Point. The copper-bearing formation between these limits dips N. 33° E., at the first locality, to south of east at the last, and the veins are nearly at right angles to the formation. The Central mine is situated in sec. 23, T. 58 N., R. 31 W., about 18 miles northeast of Calumet. Here there has been a northerly sliding of the formations above the Kearsarge conglomerate, as a result of which the copper vein in the overlying formations is found to stop abruptly at the Kearsarge conglomerate. In this mine is the eastern edge of the basin in which the Kearsarge conglomerate was deposited.

NEWETT,[72] in 1895, gives a sketch of the Marquette iron-bearing district of Michigan, and publishes a geological map of the district, compiled from a map of the Upper Peninsula in the possession of the Michigan Geological Survey. The iron ores occur in the Huronian rocks, of which there are some thirty members. This series of rocks has been subjected to enormous lateral pressure, resulting in foldings in the strata. In the folds the ore is found generally in lenticular masses. The Huronian rocks are cut by eruptive rocks, which have played an important part in assisting in the concentration of the ores.

CLEMENTS,[73] in 1895, describes the volcanic rocks of the Michigamme district of Michigan. The succession in the district from the base up is: (1) Granite and gneiss, cut by basic dikes; (2) quartzose limestone formation, with an estimated thickness of 1,500 to 2,000 feet; (3) a great series of volcanics, with an average thickness of about 3,000 feet; (4) a set of sedimentaries consisting of quartzites, slates, and iron formation material. The volcanics include apobasalts, apoandesites, and aporhyolites, each occurring both as lavas and as tuffs. The lavas are frequently amygdaloidal.

VAN HISE,[74] in 1896, describes base-levels in the crystalline rocks of central Wisconsin and Keweenaw Point. In the Wisconsin district the Archean and Huronian rocks occupying the area are truncated to an even base-level with an apparent southerly slope. The altitude is about 1,450 feet.

On Keweenaw Point the peaks of the main trap range rise to so nearly the same altitude that they form an apparent plain, which is considered an ancient base-level. The altitude of this plain is about 1,350 feet. Certain peaks, consisting of hard quartz porphyry and felsite, have resisted weathering, and stand above this plain.

The central Wisconsin plain has not been so deeply dissected as the Keweenaw Point area, but this is explained by the fact that it is not so near either Lake Superior or Lake Michigan, and therefore erosion has not been so effective over it.

From the proximity of the central Wisconsin and Keweenaw Point base-levels, and from the fact that they have nearly the same altitude, it is concluded that the base-levels of the two districts are probably but parts of a far more extensive base-leveled region resulting principally from the subaerial erosion of Cretaceous time, and perhaps also in part from the marine denudation of the Cretaceous.

GRESLEY,[75] in 1896, describes peculiar markings in iron ore from the Chapin mine of Iron Mountain, Michigan, which are thought by H. S. Williams, by Schuchert, and by Walcott to be trails of organic origin.

Van Hise, Bayley, and Smyth,[76] in 1896, map and describe[a] the geology of the Marquette iron-bearing district of Michigan. The pre-Cambrian rocks of the district comprise three series, separated by unconformities. These are the Basement Complex, or Archean; the Lower Marquette, and the Upper Marquette, the two latter constituting the Algonkian for this district. All of these are cut by basic intrusives. The pre-Cambrian rocks are unconformably overlain by Cambrian sandstone.

The Basement Complex occurs in two main areas, one north of the Marquette series, called the Northern Complex, and one south of the Marquette series, called the Southern Complex. There are also isolated areas within the Algonkian. The oldest rocks of the Basement Complex are thoroughly crystalline, foliated schists and gneisses. A close field and laboratory study has failed to detect in them any evidence of sedimentary origin. These gneisses and schists have been cut by various igneous rocks at different epochs. The latter occur both in the form of great bosses and in dikes, sometimes cutting, sometimes parallel to, the foliation of the rocks. In the area of the Northern Complex there have been volcanic outbursts, and a vast series of lavas, agglomerates, greenstone conglomerates, and tuffs have been piled up. By far the greater part of the volcanic material is of an intermediate or basic character.

The Northern Complex is treated under the divisions of Mona schists, Kitchi schists, gneissoid granites, hornblende syenites, basic dikes, acid dikes, peridotite, and ferruginous veins. The Mona and Kitchi schists are greenstone schists, which are believed to be largely recrystallized volcanic materials. Their original forms included both tuffs and lavas. The gneissoid granites and syenites are plutonic intrusive rocks within the greenstone schists. The basic dikes are mainly diabase. The peridotite is older than the Cambrian sandstone and younger than the greenstone schists of the Basement Complex. The ferruginous veins are believed to be water deposited, and were formed previous to the deposition of the Lower Marquette series.

The Southern Complex differs from the Northern Complex in the smaller quantity of greenstone schists in the former and in the presence in it of the micaceous and hornblendic schists and the Palmer gneiss. It is treated under the divisions micaceous schists, amphibole schists, gneissoid granites, Palmer gneiss, and intrusives. The micaceous schists include muscovite schists, biotite schists, feldspathic biotite schists, and hornblendic biotite schists. They are thought to be mashed acid eruptives. The amphibole schists include greenstone schists, hornblende schists, and micaceous hornblende schists. They

[a] The Algonkian rocks are described by Van Hise; the Basement Complex and later igneous rocks are described by Bayley; the Republic trough is described by Smyth.

are shown to be mashed basic eruptives. The granites and dike materials are similar in essential features to the corresponding rocks of the Northern Complex. The granites are younger than the schists, since dikes from them intrude the schists. The Palmer gneisses occur only on the borders of the granite areas, between these and the Marquette sedimentaries, and are apparently in most cases extremely mashed phases of the granites.

The isolated areas of the Fundamental Complex within the Algonkian are chiefly gneissoid granites and schistose greenstones that differ in no essential respect from the corresponding rocks of the Northern Complex and the Southern Complex.

The Lower Marquette series is composed of the following formations, given from the base upward: The Mesnard quartzite, the Kona dolomite, the Wewe slate, the Ajibik quartzite, the Siamo slate, and the Negaunee iron formation. There is no break between these formations; the series is a continuous one.

The Mesnard quartzite is chiefly a metamorphosed sandstone. However, at the bottom of this formation is a conglomerate, which in grading into the sandstone passes through slate and graywacke. The conglomerate is basal, being composed of detritus from the Basement Complex. At the top of the formation is a slate. The Mesnard quartzite is the first deposit of the westward-transgressing Lower Marquette sea. By the time the sea had advanced westward a short distance upon the Marquette district the Kona dolomite began to be formed, and hence the Mesnard formation is confined to the eastern part of the district. The thickness of the Mesnard quartzite is from 150 to 670 feet.

The Kona dolomite is largely an altered limestone, but it includes interstratified layers of slate, graywacke, and quartzite, with gradation phases between these and the pure dolomite. The Kona dolomite, like the Mesnard quartzite, is confined to the eastern part of the district. The dolomite varies through a slate into the Mesnard quartzite below, and by a lessening of the calcareous constituent gradually passes into the Wewe slate above. The thickness is from 425 to 1,375 feet.

The Wewe slate is chiefly a metamorphosed mudstone, but with the slates are conglomerates, quartzites, graywackes, mica slates, and mica schists. The Wewe slate, like the two previous formations, is confined to the eastern part of the district. The formation grades into the Kona dolomite below and the Ajibik quartzite above. The thickness is from 550 to 1,050 feet.

The Ajibik quartzite is mainly a metamorphosed sandstone, which in different parts of the district, depending upon various conditions, has been transformed into quartzite, cherty quartzite, ferruginous quartzite, ferruginous cherty quartzite, quartz rock, and quartzite breccia. The time of the Ajibik quartzite marks a rapid advance to the west of the Lower Marquette sea, and therefore the formation extends to the western end of the district. In the eastern part of the area the Ajibik quartzite grades down into the Wewe slate, but for the major part of the district it rests unconformably upon the Basement Complex. At many localities contacts and basal conglomerates are known. The Ajibik quartzite grades above either into the Siamo slate or into the Negaunee iron formation. The thickness is from 700 to 900 feet.

The Siamo slate is chiefly an altered mudstone, although locally it is a graywacke or quartzite. The larger area of exposure of the formation is confined to the eastern part of the district, although a belt of the formation runs near the north side of the Marquette series to the west end of the district. The Siamo slate grades into the Ajibik quartzite below and into the Negaunee iron formation above. The thickness is from 600 to 1,200 feet.

The Negaunee iron formation is nonfragmental, heavily ferruginous throughout, and contains the greater iron-ore deposits of the district. The formation comprises sideritic slate, which may be grüneritic, magnetitic, hematitic, or limonitic; grünerite-magnetite schist; ferruginous slate; ferruginous chert; jaspilite, and iron ore. Large quantities of intrusive greenstones are associated with the formation, the masses of which vary in magnitude from great bosses 2 miles or more long and half a mile wide to small dikes. The largest area of the Negaunee formation is in the east-central part of the district. From this area two belts extend west to the western end of the district. On the whole the formation is soft, and occupies lowlands between the more resistant greenstones and the Ajibik quartzite. The formation is underlain by the Siamo slate or Ajibik quartzite, into which it grades, and is overlain unconformably by the Upper Marquette series.

The sideritic slate is the original form from which the other varieties of rock have developed. The grünerite-magnetite schists were formed by partial recrystallization of the silica, by oxidation of the iron oxide in part to magnetite, by union of a part of the silica and iron protoxide, producing grünerite, and with the loss of carbon dioxide. The ferruginous slates are the direct result of the decomposition of the iron carbonate and the peroxidation of the iron, with partial or complete recrystallization of the silica. The ferruginous cherts differ from the ferruginous slates in that the iron oxide and the chert are largely concentrated into alternate bands. The jaspilites differ from the ferruginous cherts in that each of the quartz grains of the chert bands is stained red by included hematite. The iron ores resulted from the concentration of the iron oxides through the agency of downward-percolating waters. These concentration bodies usually occur upon impervious basements in pitching troughs. The pitching troughs are formed by the Siamo slate, the Ajibik quartzite, a mass or dike of greenstone, or by some combination of these. The ore deposits are likely to be of large size where, as a result of the folding, the iron-bearing formation is much fractured, thus permitting the ready access of percolating waters. The ore deposits occur at the bottom of the Negaunee formation, within the Negaunee formation, and at the contact horizon between the Negaunee formation and the overlying Ishpeming formation. From the position of the ore deposits above the impervious formations it is concluded that their concentration occurred during or subsequent to the folding which took place later than Upper Marquette time.

The Upper Marquette series is composed of the following formations, in conformable succession from the base upward: Ishpeming formation, Michigamme formation, Clarksburg formation.

The Ishpeming formation includes two classes of rocks, which are called the Goodrich quartzite and the Bijiki schist. These rocks are sufficiently different to have different formation names, but the Bijiki schist in the west end of the district occupies a part of the horizon of the Goodrich quartzite in the central part.

The Goodrich quartzite includes quartzites, micaceous quartz schists, mica schists, mica gneisses, and at the base a basal conglomerate. For the major part of the district this conglomerate rests upon the Negaunee formation, and the rock is an ore, chert, jasper, and quartz conglomerate. At a few places the Archean rocks are subjacent, and here their materials predominate in the conglomerate. The Goodrich quartzite is confined to the central and western parts of the district. For the major part of the district it rests unconformably upon the Negaunee formation. In places erosion has cut through the Negaunee formation into the Ajibik quartzite, and in a few cases even to the Archean, and here the Goodrich quartzite may be found resting on the lower formations. For the greater part of the area the Goodrich quartzite grades up into the Michigamme or Clarksburg formation, but in the northwestern part of the district it passes up into the Bijiki schist. The thickness is from 600 to 1,550 feet.

The Bijiki schist is a banded grünerite-magnetite schist, which has been derived by metasomatic and dynamic processes from an impure siderite. It is confined to the western part of the district. The Bijiki schist grades into the Goodrich quartzite below and into the Michigamme formation above. The thickness is from zero to 520 feet.

The Michigamme formation includes slates, graywackes, mica schists, and mica gneisses. The formation is exposed in a single large belt, running from the center to the western end of the district.

It grades below into the Goodrich quartzite, Bijiki schist, or Clarksburg formation. The thickness can not be accurately estimated, but it is probably as much as 2,000 feet.

The Clarksburg formation is composed predominantly of volcanic materials, embracing basic lava flows, tuffs, ashes, and breccias, which locally are interleaved with or grade into slate, graywacke, or conglomerate. Much of the material has been profoundly metamorphosed, and schist conglomerates, mica schists, and hornblende schists have resulted. All of these rocks are cut by dikes and masses of greenstone. The formation is confined to the south-central part of the district. The volcanic material was poured out from a number of vents, the more important ones which have been recognized being located near Clarksburg, Greenwood, and Champion. The formation grades into the Ishpeming formation or the Michigamme formation below, and into the Michigamme formation above. The Clarksburg formation belongs in age either between the Goodrich quartzite and the Michigamme formation or near the base of the latter. No estimate of the thickness can be given.

The igneous rocks, other than those of the Clarksburg formation, are divided for convenience in discussion into two classes, in the first of which are placed those associated exclusively with the beds below the Clarksburg formation, and in the other those cutting also the beds above the Clarksburg. The rocks are all basic. The older rocks occur as dikes, bosses, sheets, and tuff beds, although the latter two are subordinate. The post-Clarksburg greenstones comprise only dikes and bosses. It is conjectured that these later greenstones may be the equivalents of some of the Keweenawan eruptives.

Evidence of the unconformity between the Lower Marquette series and the Basement Complex is clear and abundant. At numerous places in the district the actual contacts of the basal conglomerate of the Marquette series and the Fundamental Complex may be seen. In all of these cases the detritus is most distinctly waterworn, and, while the major part of the material in each case has been derived from the immediately subjacent part of the Basement Complex, other material not occurring in the immediate neighborhood is found, thus showing conclusively that these rocks are not reibungs or fault breccias. The principal localities at which contacts are well exposed may be mentioned.

At the east end of the south side of the Marquette district there are several localities, from Lake Superior to west of Lake Mary, where a conglomerate is found bearing numerous bowlders of granite, gneiss, and schist, identical with the rocks constituting the Basement Complex immediately adjacent. In secs. 22 and 23, T. 47 N., R. 26 W., are two islands of the Basement Complex, about which are found magnificent exposures of great bowlder conglomerate and recomposed granite, resting with visible contact upon the Basement Complex and composed of material mainly derived from it. South of the Cascade range there are again a number of localities, from secs. 34 to 32, T. 47 N., R. 26 W., where there are basal conglomerates; the great bowlders again being mainly identical with the adjacent granites, gneisses, and schists of the Basement Complex. South of Summit Mountain, in the west half of sec. 25, T. 47 N., R. 27 W., is an exposure of the basal conglomerate. The conglomerate grades downward into a schist which is scarcely distinguishable from the Palmer gneiss, with which it is in contact. The next contact to the west is in sec. 28, T. 47 N., R. 27 W., where the phenomena are similar to those south of Summit Mountain. At the end of the Republic trough a conglomerate hangs with visible contact upon the flank of the Archean granite, bearing well-rounded waterworn bowlders from the granite.

At the north side of the Lower Marquette series and near the east end of the district there is exposed a magnificent basal conglomerate, about 3 miles west of Marquette, north of Mud Lake. The next contacts to the west are at the base of the quartzite east and west of Teal Lake. At one place here the relations are such that the layers of the conglomerate cut across the foliation of the subjacent schists at an acute angle. Still farther west, in sec. 30, T 48 N., R 28 W., contacts are found in a number of places. West of this point the only actual contact known is north of the Michigamme mine.

The unconformity between the Lower Marquette and Upper Marquette series is also well marked. At the close of Lower Marquette time the land was raised above the sea and gently folded and eroded, and the Upper Marquette sediments were later laid down unconformably upon this floor. In general the discordance between the Lower Marquette series and the succeeding series is not great, being measured frequently by 5° to 10°, at other times by 10° to 15°, and it is only rarely that the plications of the lower series are such as to make the beds abut perpendicularly against those of the overlying series. Erosion has cut deeper in the Lower Marquette series in some places than in others, so that the Upper Marquette series rests upon different members of the lower series. At the east end of the area it left a very considerable thickness of the iron-bearing formation, but in places to the west this formation is quite cut out. Indeed, in places erosion cut through the Siamo slate and the Ajibik quartzite, and in some places even into the Basement Complex. This particularly occurs in the western and southwestern parts of the district, west of Champion and along the Republic trough, where but few members of the Lower Marquette series were deposited. Even within a short distance the differential erosion was considerable. For instance, at the south end of the Republic trough the variation was more than 1,500 feet.

The Marquette district has been folded in a complex manner. The largest but least conspicuous fold of the district is an anticline having a north-south axis, running through the city of Marquette. This great fold has, especially near its crown—that is, for the eastern 6 or 8 miles of the district—folds of the second order superimposed upon it, making this part of the fold an anticlinorium. The other major anticline belonging to this system of folds is one running north and south through the east end of Michigamme Lake. The major part of the district has been affected, however, by much more effective pressure in a north-south direction, so that the folds in an east-west direction are much more conspicuous than the north-south folds of greater wave length and greater amplitude. As a result of the north-south pressure, the Upper and Lower Marquette series together have been bent into a great abnormal synclinorium. This synclinorium is of a peculiar and complicated character. The Algonkian rocks on either side of the trough have moved over the more rigid Archean granite, and, as a consequence, on each side of the Algonkian trough a series of overfolds plunge steeply toward its center, producing a structure resembling in this respect the composed fan structure of the Alps. There is, however, this great difference between the Marquette structure and that of the Alps, that in passing from the sides of the trough toward the center newer rocks appear rather than older ones, so that in the center of the synclinorium the youngest rocks are found. It is as if the composed fan folds of the Alps were sagged downward, so that the structure as a whole is a synclinorium rather than an anticlinorium. This form of folding has been elsewhere defined by Van Hise [a] as an abnormal synclinorium. The folding is closer in the western part of the district than to the east. The strikes of most of the exposures of the district are mainly controlled by the east-west folds, but, at the east and west ends of the areas of the formations the larger north-south folds already described control.

WADSWORTH,[77] in 1898, describes the origin and mode of occurrence of the Lake Superior copper deposits and the age of the copper-bearing series. A reexamination of the Douglass Houghton and Hungarian River areas shows that the Eastern sandstone passes under the lavas with increasing dip, and that the junction is not a fault junction but that of a lava flow upon an underlying soft sand and mud. It is held that the Eastern sandstone is of Potsdam age, and underlies the copper-bearing series, the first lava of that series having flowed out upon the sandstone. The basaltic rocks forming the Bohemian Moun-

[a] Van Hise, C. R., Principles of North American pre-Cambrian geology: Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 1, 1896, p. 612.

tains present phenomena which indicate their eruption subsequent to the formation of the main deposits of the region, although the question is as yet open. Subsequent to the deposition of the Keweenawan a fissure was formed near the contact of the Eastern sandstone and the lavas, along which normal faulting occurred, the copper-bearing series forming the overhanging side of the fault. As to the nature of the displacement, however, more evidence is needed. The copper occurs in fissure veins, in melaphyres, and in conglomerates.

Boss,[78] in 1898, describes the dikes associated with the ore deposits of the Gogebic iron range. They are dioritic and more or less altered; they are approximately at right angles with the dip of the formation they cut, and the greater number of them have an average easterly dip of 15° to 18°; sometimes they are folded in such a manner as to form long synclinal basins with eastward pitch. In a majority of cases mining exploitation has shown a succession of dikes, one below the other, and ferruginous quartzite of varying thickness immediately underlying each dike and forming the cap of the succeeding deposit of ore.

Lane,[79] in 1898, gives a detailed account of the geology and petrography of Isle Royal, Lake Superior. The island trends north of east and the edges of the strata outcrop in approximately this direction. The rocks are interbedded conglomerates, sandstones, and traps of Keweenawan age, dipping in a southerly direction at angles varying from 8° to 32°, the higher dips in general to the north. Faults are shown to exist at various places with directions approximately northeast-southwest and northwest-southeast, and the probable existence of other more extensive faults running entirely across the island is indicated. Detailed sections, with correlations with the Keweenawan of other parts of Lake Superior, are given.

Hubbard,[80] in 1898, discusses the geology of Keweenaw Point with particular reference to the felsites and their associated rocks. The term felsite is used to include all the very fine-grained and highly acidic igneous rocks. These occur at a number of horizons below the Bohemian conglomerate, so called from the fact that it skirts the northern side of the Bohemian range near the northeast end of Keweenaw Point. The outcrops of felsite studied occur in sec. 30, T. 58, R. 27 (New England or Keystone location); sec. 25 (?), sec. 35 (Fish Cove), secs. 26 and 27 (Little Montreal River), all in T. 58, R. 28; secs. 29 and 30, T. 58, R. 28 (Bare Hill and westward therefrom); secs. 23 and 24, T. 58, R. 29 (Mount Houghton) and both eastward and westward therefrom; sec. 10, T. 57, R. 31 (Suffolk location, Praysville); sec. 4, T. 56, R. 32 (Allouez Gap, east of the Kearsarge and Wolverine mines); sec. 30, T. 56, R. 32 (falls on branch of Trap Rock River); sec. 36, T. 56, R. 33 (Douglass Houghton Falls), and sec. 1, T. 55, R. 33 (Hecla and Torch Lake Railroad).

The evidence concerning the source of the Keweenawan lavas is considered, and it is concluded that they may probably have come from a higher level somewhat back from the edges of the present Keweenawan basin.

With this probability in mind the following hypotheses are suggested:

1. The irregularities in the lower beds of the Keweenaw series in the Portage Lake area, contrasted with the greater regularity of the higher part of the series, suggest that in this area, near the contact between the Keweenaw series and the Eastern sandstone, we are on the edge of an early Keweenawan or pre-Keweenawan basin.

2. If the lower beds of the Keweenaw series near Portage Lake rested on the sides of a basin, the later beds of the series from here eastward lay at a higher altitude and, excepting those of the south trap range, were eroded in pre-Potsdam time, together, possibly, with a part of the underlying Archean.

3. The porphyries found on Keweenaw Point at the contact between the Keweenaw series and the Potsdam sandstone may be in part either,

a. Marginal facies of the underlying Archean;

b. Intrusive in the early Keweenawan;

c. Early interbedded flows of the Keweenaw series; or

d. Remnants of late Keweenawan intrusions by which the eastern margin of the series was broken up and its degradation hastened.

Seaman and Sutton,[81] in 1898, discovered east of Little Presque Isle River, in the Gogebic district, a quartzite and conglomerate beneath the limestone of the Lower Huronian series. The conglomerate rests with sharp contact on steeply inclined green schists of the Archean. The unconformity between the Lower Huronian and the Archean had been previously inferred from general field relations but had not been actually observed. This exposure is diagrammatic in its clearness. The quartzite is believed to correspond to the Mesnard quartzite beneath the dolomite in the Marquette district.

Clements, Smyth, Bayley, and Van Hise,[82] in 1899, describe the Crystal Falls iron-bearing district of Michigan.

The rocks of the district comprise two groups, separated by unconformities. These are the Archean and the Algonkian. The Algonkian includes both the Lower Huronian and the Upper Huronian series, and these are also separated by unconformities. The terms Lower Huronian and Upper Huronian are applied to the series which occur in this district because they are believed to belong to the same geological province as the Huronian rocks of the north shore of Lake Huron, and to be equivalent to the Lower Huronian and Upper Huronian series which there occur.

The Archean is believed to be wholly an igneous group, and therefore no estimate of its thickness can be given. It covers a broad area in the eastern part of the district, and from this several arms project west. West of the main area there are two large oval areas of Archean.

The Lower Huronian series, from the base upward, comprises the Sturgeon quartzite, from 100 to more than 1,000 feet thick; the Randville dolomite, from 500 to 1,500 feet thick; the Mansfield slate, from 100 to 1,900 feet thick; the Hemlock volcanic formation, from 1,000 to 10,000 or more feet thick; and the Groveland formation, about 500 feet thick. A minimum thickness for the series is about 2,200 feet, and a possible maximum thickness is more than 16,000 feet. However, in the latter case a large part of the series is composed of volcanic material. It is not likely that the sediments at any one place are as much as 5,000 feet thick.

The Upper Huronian is a great slate and schist series, which it is not possible to separate on the maps into individual formations. It is impossible to give even an approximate estimate of the thickness of this series.

Various igneous rocks intrude in an intricate manner both the Upper Huronian and the Lower Huronian series.

In the following paragraphs the descriptions of the formations are summarized somewhat more in detail.

Archean.—The Archean consists mainly of massive and schistose granites and of gneisses. Nowhere in the Archean have any rocks of sedimentary origin been discovered. The Archean has been cut by various igneous rocks, both basic and acidic, at different epochs. These occur in the form both of bosses and of dikes, the latter sometimes cutting, but more ordinarily showing a parallelism to, the foliation of the schistose granites. The granites must have formed far below the surface, and therefore must have been deeply denuded before the transgression of the Lower Huronian sea. The Archean granites and gneisses and the earlier intrusives alike have been profoundly metamorphosed, and at various places have been completely recrystallized.

Lower Huronian.—The Sturgeon quartzite, the first deposit of the advancing sea, when formed consisted mainly of sandstone, but in places at the base it consisted of coarse conglomerate. The conglomerate is best seen in the Sturgeon River tongue. Elsewhere evidence of conglomeratic character at the base of the formation is seen, but the metamorphism has been so great as nearly to destroy the pebbles. However, in the Sturgeon River tongue is a great schistose conglomerate which, while profoundly metamorphosed, still gives evidence of the derivation of its material from the older Archean rocks. The sandstone has been changed to a vitreous, largely recrystallized quartzite, which now shows only here and there vague evidence of its clastic character.

The Sturgeon formation varies in thickness from probably more than 1,000 feet in the Sturgeon River tongue to less than 100 feet at places in the Felch Mountain range, and is altogether absent in the northeastern part of the district.

In the southeastern part of the district the Sturgeon quartzite is overlain by the Randville dolomite. In the central part of the district the quartzite between the Archean and the Randville is so thin that it can not be represented on the maps as a separate formation. In the northeastern part of the district a quartzite, resting on the Archean, but occupying a higher position stratigraphically than the Randville dolomite, is overlain by an iron-bearing formation. It appears, therefore, that the Sturgeon sea gradually overrode the district, and that at the time the Sturgeon quartzite was deposited in the southeastern part of the district the Archean was not yet submerged in the central and northeastern parts. However, since the quartzite resting on the Archean in the latter area can not be separated lithologically from the Sturgeon quartzite, both are given the same formation color, but the later quartzite is given a separate letter symbol. The quartzite color therefore represents the transgression deposits of the same general lithological character, rather than a formation all parts of which have exactly the same age. While nowhere in the district is there any marked discordance between the schistosity of the Archean and the Sturgeon quartzite, the conglomerates at the base of the latter formation in the Sturgeon River tongue are believed to indicate a great unconformity between the Archean and the Lower Huronian series. The change from the Sturgeon deposits to those of the Randville was a transition.

The Randville dolomite is a nonclastic sediment, and is believed to mark a period of subsidence and transgression of the sea to the northeast, resulting in deeper water for much of the district. Since the Randville dolomite has its full thickness on the Fence River just east of the western Archean oval, and does not appear at all about the Archean oval a short distance to the northeast, it is probable that the shore line, during Randville time, was between these two areas and that the land arose somewhat abruptly toward the northeast. As the Randville formation has a thickness of 1,500 feet, it probably represents a considerable part of Lower Huronian time.

Following the deposition of the Randville dolomite, deposits of very different character occur in different parts of the district. These deposits are: (1) The Mansfield formation, (2) the Hemlock volcanic formation, and (3) the Groveland formation.

The Mansfield formation was a mudstone, which has subsequently been transformed into a slate or schist. The Hemlock formation is mainly a great volcanic mass, including both basic and acidic rocks, lavas, and tuffs, but it contains also subordinate interbedded sedimentary rocks. This formation occupies a larger area than any other of the Lower Huronian formations, and is perhaps the most characteristic feature of the Crystal Falls district. The Groveland is the iron-bearing formation. It includes sideritic rocks, cherts, jaspilites, iron ores, and other varieties characteristic of the iron-bearing formations of the Lake Superior region. In all important respects these rocks are similar to those of the Negaunee formation of the Marquette district, with the exception that in the southeastern part of the Crystal Falls district, associated with the nonclastic material there is a considerable proportion of clastic deposits. The Groveland formation contains iron carbonate and possibly glauconite, from which its other characteristic rocks were derived.

The variability in the character of the deposits overlying the Randville formation is probably caused by the great volcanic outbreaks in the western part of the district. In the southern and southeastern parts the deposit overlying the Randville formation is the Mansfield slate and schist. North of Michigamme Mountain and of the Mansfield area the Mansfield formation is replaced along the strike by the Hemlock volcanic formation, which directly overlies the limestone for most of the way about the western Archean oval. The effect of the volcanic outbreak apparently did not reach so far as the northeastern part of the district.

Overlying the Mansfield formation in the southeastern part of the district and the Randville formation in the central part is the Groveland iron-bearing formation. In the Mansfield slate area the iron-bearing rocks appear near the top of the Mansfield formation intercalated with the slates. The Groveland formation can not be certainly traced farther north than the northeastern portion of the western Archean oval. It is apparently replaced along the strike by the Hemlock volcanics.

In the northeastern part of the district the Groveland formation, equivalent to the Negaunee formation of the Marquette district of Michigan, is found above the Ajibik formation. The occupation, in the western part of the district, by the Hemlock volcanics of the same part of the geological column that is occupied by the Hemlock volcanics east of the western Archean oval, the Mansfield slate, and the Groveland formation is explained by the fact that in the western part of the district the volcanoes broke out and there continued their activity longest. While the volcanic rocks were being laid down north of Crystal Falls the Mansfield formation was being deposited in the southeastern part of the district. This activity continued there through the time in which the Groveland formation was being deposited in other parts of the district.

From the foregoing it appears that the Hemlock formation in the western part of the district is equivalent—

1. East of the western Archean oval, to the Hemlock volcanics found there and the overlying Groveland formation.

2. At Michigamme Mountain, to the Mansfield slates and the Groveland formation.

3. In the Mansfield area, to the Mansfield slates and the Hemlock volcanics occurring there.

4. In the southeastern part of the district, to the Mansfield and Groveland formations.

The replacement of an iron-bearing formation by the great volcanic formation just described is exactly paralleled in the Upper Huronian rocks on the Penokee iron-bearing series, where the pure iron-bearing formation is replaced at the east end of the district by a great volume of volcanic rocks intercalated with slates and containing bunches of iron-formation material.

Following the deposition of the Lower Huronian series the region was raised above the sea and eroded to different depths in different places. In the Felch Mountain range the only formations above the Randville dolomite are a thin bed of slate and the Groveland iron formation. In the northeastern part of the district only a thin belt of iron-formation rocks remains. In the central and western parts of the district there is a great thickness of volcanics. This, however, does not imply a difference of erosion equal to the difference in thickness of these rocks, for doubtless when the volcanics were built up there was contemporaneous subsidence, so that at the end of Lower Huronian time there may have been little variation in the elevation of the upper surface of the series, but very great differences in its thickness.

Upper Huronian.—After the Lower Huronian series was deposited the district was raised above the sea, may have been greatly folded, and different parts were eroded to different depths.

Following the earth movements and erosion, the waters for some reason advanced over the district, and the Upper Huronian series was deposited. The basal horizon was a conglomerate, which has, however, very different characters in different parts of the district.

In the eastern half were Archean rocks, the Sturgeon quartzite, the Mansfield slate, and the Groveland iron formation. Upon these was deposited a sandstone which locally was very ferruginous. This has been changed into a ferruginous quartzite. The typical occurrence of this quartzite is at the end of the Felch Mountain range. It also appears between the Archean ovals in the northeastern part of the district. If distinct conglomerates were formed at the bottom of this quartizite, they are buried under glacial deposits or have disappeared as the result of metamorphism.

In the western part of the district the rocks of the Lower Huronian at the surface are the great Hemlock formation, and here the basal horizon of the Upper Huronian is a slate or slaty conglomerate, the fragments of which are derived mainly from the underlying Hemlock formation. The sandstones and conglomerates varied upward into shales and grits, which have been altered into mica slates and mica schists. After a considerable thickness of mudstone and grit was deposited, there followed a layer of combined clastic and nonclastic sediments, the latter including iron-bearing carbonates. These appear to be at a somewhat persistent horizon, and in this belt are found the iron-formation rocks and iron ores in the Upper Huronian in the vicinity of Crystal Falls. Above these ferruginous rocks there was deposited a great thickness of shales and grits which have been transformed into mica slates and mica schists.

Since the deposition of the Upper Huronian the rocks of the district have been folded. The more complex folds vary from a north-south to an east-west direction. The closer folds in the northeastern part of the area are nearly north-south. In the central part of the area the closer folds strike northwest-southeast. In the eastern and southeastern parts of the district the closer folds are nearly east-west. All of these folds have steep pitches.

Subsequent to or during the late stage of this time of folding there was a period of great igneous activity, probably contemporaneous with the Keweenawan. At this time there were introduced into both the Lower and the Upper Huronian vast bosses and numerous dikes. The intrusives vary from those of an ultrabasic character, such as peridotites, through those of a basic character, such as gabbros and dolerites, to those of an acidic character, such as granites. These intrusives, while altered metasomatically, do not show marked evidence of dynamic metamorphism; therefore the conclusion that they were introduced later than the period of intense folding already described.

Cambrian rocks overlie unconformably the rocks above described.

Descending succession of formations in the Marquette, Crystal Falls, and Menominee districts.

Marquette.	Crystal Falls.	Menominee.
UPPER MARQUETTE: 1. Michigamme formation, bearing a short distance above its base an iron-bearing horizon, and being replaced in much of the district by the Clarksburg volcanic formation. 2. Ishpeming formation, being composed of the Goodrich quartzite in the eastern part of the district, and of the Goodrich quartzite and the Bijiki schists in the western part of the district.	UPPER HURONIAN: 1. Michigamme formation, bearing a short distance above its base an iron-bearing horizon. 2. Quartzite in eastern part of the district.	UPPER MENOMINEE: 1. Great Slate formation.
Unconformity.	Unconformity.	Unconformity.
LOWER MARQUETTE: 1. Negaunee iron formation, 1,000 to 1,500 feet thick. 2. Siamo slate, in places including interstratified amygdaloids, 200 to 625 feet thick. 3. Ajibik quartzite, 700 to 900 feet thick. 4. Wewe slate, 550 to 1,050 feet thick. 5. Kona dolomite, 550 to 1,375 feet thick. 6. Mesnard quartzite, 100 to 670 feet thick.	LOWER HURONIAN: 1. The Groveland formation, about 500 feet thick. 2. Hemlock volcanic formation, 1,000 to 10,000 feet thick. In western part of district also occupies place of (1) and (3). 3. Mansfield formation, 100 to 1,900 feet thick. 4. Randville dolomite, 500 to 1,500 feet thick. 5. Sturgeon quartzite, 100 to 1,000 feet thick.	LOWER MENOMINEE: 1. Vulcan iron formation containing slates. 2. Antoine dolomite. 3. Sturgeon quartzite.
Unconformity.	Unconformity.	Unconformity.
ARCHEAN.	ARCHEAN.	ARCHEAN.

SEAMAN,[83] in 1899, gives a summary of the geological history of the Keweenawan copper range in Michigan, Wisconsin, and Minnesota. No new facts on the geology of the region are added to those already recorded.

DUPARC,[84] in 1900, describes the copper-bearing (Keweenawan) rocks of the northwest extremity of Keweenaw Point, Michigan. The article is throughout merely a summary of previous reports on this area by the geologists of the Michigan and United States surveys, and this, moreover, without a single reference to such reports.

VAN HISE and BAYLEY,[85] in 1900, describe and map the geology of a portion of the Menominee iron district of Michigan.

The pre-Cambrian succession is as follows:

Algonkian	Upper Menominee	Hanbury slate. Vulcan formation, subdivided into the Curry ore-bearing member, Brier slate, and Traders ore-bearing member.
	Unconformity.	
	Lower Menominee	Negaunee formation. Randville dolomite. Sturgeon quartzite.
	Unconformity.	
Archean		Granites and gneisses, cut by granite and diabase dikes. Quinnesec schists, cut by acidic and basic dikes and veins.

In general the Algonkian rocks constitute a trough bounded on the north by the Archean rocks.

Archean.—The Quinnesec schists are dark-green or black basic schists and spheroidal greenstones, cut by large dikes of gabbro, diabase, and granite, and by smaller dikes of a schistose quartz porphyry. These occur in two areas, one along Menominee River to the south of the Huronian rocks, and another in the west-central end of the district.

Bordering the Algonkian trough on the north is a complex of granites, gneisses, hornblende schists, and a few greenstone schists, all cut by dikes of diabase and granite. This complex is called the Northern Complex. Most of the Archean rocks are igneous. Although there is no evidence of this, some of the fragmental tuffs may have been water deposited. The Quinnesec schists and the Northern Complex are called Archean because they resemble lithologically other areas of Archean rocks in the Lake Superior country, and they both underlie the Algonkian series. The Northern Complex underlies the series with unconformity. The Quinnesec schists have not been observed in contact, and hence the presence or absence of a normal erosion unconformity can not be inferred.

Lower Menominee series.—The formations of the Lower Menominee series are observed only in the center and on the northern side of the Menominee trough. The Sturgeon formation is composed mainly of a hard, white vitreous quartzite forming a continuous border of bare hills bordering the Archean complex. At its base is a coarse conglomerate made up of débris from the underlying Archean complex. The belt is in general a southward-dipping monocline with dips varying from 25° to perpendicularity, although there are many reverse dips to the north. Its thickness is placed at from 1,000 to 1,250 feet.

Above, the Sturgeon quartzite grades into the Randville formation, which is mainly a homogeneous dolomite interstratified with siliceous or argillaceous layers. This formation appears in three belts. The northern one is just south of the belt of the Sturgeon quartzite. The central belt is on the north side of Lake Antoine for a portion of its length, passes eastward between the Cuff and the Indiana mines, and ends at the bluff known as Iron Hill, in the east half of sec. 32, T. 40 N., R. 29 W. The southern belt of dolomite extends all the way from the western side of the sandstone bluff west of Iron Mountain to the village of Waucedah, at the eastern end of the mapped area. Structurally the northern belt of dolomite is a southward-dipping monocline, while the two southern belts are anticlines. The thickness is not determined on satisfactory evidence, but is probably 1,000 feet or more. The Randville formation is found, in a number of mines, in contact with the basal formation of the Upper Menominee series. Here there is a coarse conglomerate in the basal part of the overlying formation, indicating unconformity.

The Negaunee formation, overlying the Randville dolomite, is represented in the district by so few and so small outcrops that it is mapped with the Vulcan formation. Its presence is inferred mainly from the occurrence of abundant iron-formation débris in the basal conglomerate of the Upper Menominee formation, showing that the Lower Menominee iron-bearing series must have been present. In the Marquette district an iron-bearing formation (the Negaunee) occupies an exactly similar stratigraphical position.

Upper Menominee series.—The formations between the unconformity at the top of the Lower Menominee and the unconformity at the base of the Lake Superior sandstone are placed in the Upper Menominee series. These occur in two great series, the Vulcan and the Hanbury.

The Vulcan formation is unconformable above the upper part of the Lower Huronian, which for the most of the district is the Randville formation, and unconformable below the Hanbury slate. For parts of the district the Vulcan iron-bearing formation does not appear at all between the dolomite and the slate, and its absence is explained by the unconformity between the Vulcan formation and the Hanbury slate. The Vulcan formation embraces three members. These are, from the base up, the Traders iron-bearing member, the Brier slate, and the Curry iron-bearing member. They are mapped as a single formation. The principal area of the Vulcan iron formation is in the belt, 900 to 1,300 feet wide, following the sinuosities of the southern border of the southern belt of Randville dolomite. It is generally absent north of the southern belt, except at the east end, where it appears at the Loretto mine and eastward. The second important area of Vulcan iron formation stretches off about 5 miles along the south side of the central dolomite belt running north of Lakes Antoine and Fumee, and ending somewhere about the east line of R. 30 W. At the east end of the dolomite area the iron-bearing formation appears in the lean slates at Iron Hill. The third stretch of country in which the iron-bearing beds are to be expected is that which borders the northern dolomite belt, but while pits have shown the existence of the formation here its distribution is unknown. The other areas in which the Vulcan formation may occur are those bordering the Quinnesec schists, but this has not yet been determined.

The Traders member consists of ferruginous conglomerate, ferruginous quartzite, heavily ferruginous quartzose slates, and iron-ore deposits. The Brier member consists of heavy black ferruginous and quartzose slates. The Curry member consists of interbedded jaspilite, ferruginous quartzose slates, and iron-ore deposits. The relations of the Traders and Brier Hill members where there has been no disturbance of the strata are those of gradation. Where there has been disturbance, as in the vicinity of Norway, there has been a zone of differential movement between the two, resulting in slickensides and brecciated zones. Between the Brier slates and the Curry member there is gradation.

The Vulcan formation is bent into folds of several orders of magnitude, the greater ones corresponding approximately to the folds in the underlying Randville dolomite. The total thickness of the formation is probably 600 to 700 feet.

The iron-ore deposits of large size rest upon relatively impervious formations, which are in such position as to constitute pitching troughs. A pitching trough may be made (*a*) by the dolomite formation underlying the Traders member of the Vulcan formation, (*b*) by a slate constituting the lower part of the Traders member, and (*c*) by the Brier slate between the Traders and Curry members of the Vulcan formation. The dolomite formation is especially likely to furnish an impervious basement where its upper horizon has been transformed into a talc schist, as a consequence of folding and shearing between the formations.

Unconformably above the Vulcan iron formation is the Hanbury formation, which forms three large belts in the syncline of the older rocks, and occupies a very large proportion of the district. The formation comprises clay slates, calcareous slates, graphite slates, graywackes, quartzite, ferruginous dolomite, and rare bodies of ferruginous chert and iron oxide. The formation is much thicker than any of the other formations of the district, but its thickness is probably not more than 2,000 or 3,000 feet.

SEAMAN,[86] in 1902, as a result of observations made through a long series of years, concludes that the Lower Huronian series of the Marquette district as mapped by the United States Geological Survey really consists of two unconformable series, the upper one including the Negaunee iron formation, the Siamo slate, and the Ajibik quartzite, and the lower one including the Wewe slate, the Kona dolomite, and the Mesnard quartzite. The unconformity between these two series is believed to be as great as that previously described between the Upper Huronian and the rocks underlying. The principal evidences of this are the conglomerates at the base of the Ajibik observed both east and west of Teal Lake, on Carp River, and at various localities southwest of Goose Lake, and the fact that the Ajibik quartzite comes in contact now with one member and now with another of the underlying series, indicating a preceding erosion interval great enough to allow of the deep truncation of the underlying series.

Additional evidence of faulting is noted along Carp River, in the Palmer area, and east of Teal Lake. The extremely complicated relations in the Teal Lake area seem to be fully explained by the discovery of the unconformity within the series, together with the faulting. The faults are mainly gravity faults, striking parallel to the limbs of the main Marquette syncline.

HOTCHKISS,[87] in 1903, describes and maps the Palmer area. This is far more detailed work than anything preceding. One and perhaps more east-west faults are mapped.

VAN HISE, BELL, ADAMS, MILLER, LANE, HAYES, SEAMAN, and LEITH,[88] in 1904, visited the Marquette district and made observations confirming the conclusions previously reached by geologists of the United States Geological Survey and by A. E. Seaman. Three distinct sedimentary series intruded by basic and acidic igneous rocks and separated by unconformities were noted. These lie unconformably upon a Basement Complex consisting of basic and acidic igneous rocks with small quantities of mechanical sediments and of iron formation, as previously described. The three sedimentary series are called the Upper, Middle, and Lower Marquette series. The basic portion of the Basement Complex, including greenstone schists with associated iron formation and slate, is called Keewatin, and the granites and gneisses intrusive into the Keewatin but not into the Huronian are called Laurentian.

The same authors visited the Gogebic district and particularly the areas in the vicinity of Ironwood, Bessemer, and Presque Isle River. The conclusions of Irving and Van Hise and of Seaman were confirmed. Two sedimentary series, called respectively the Upper and Lower Huronian, separated by unconformities, were observed to lie on a Basement Complex consisting of a basic division previously called Mareniscan by the United States Geological Survey, but now called Keewatin, intruded by a granitic complex called Laurentian.

SEAMAN,[89] in 1904, revised the geological maps of the Marquette, Menominee, and Gogebic districts for the Michigan exhibit at the St. Louis world's fair.

BAYLEY and VAN HISE,[90] in 1904, describe and map the geology of the Menominee iron-bearing district of Michigan. The essential facts are covered in a preliminary report.[a] An additional feature of interest is the discovery of minute granules in the Menominee iron formation similar to the greenalite granules from which the Mesabi ores are largely derived.

ROSE,[91] in 1904, discusses the geology of the Humboldt, Champion, Marquette, Michigamme, L'Anse, Republic, Crystal Falls, and Amasa districts. A number of interesting details, particularly concerning mines and magnetic lines, are added to the description of these localities, but the description of the general geology follows in general that of the United States Geological Survey monographs.

COREY and BOWEN,[92] in 1905, find evidence along Pine River that the Keewatin schists, probably the continuation of the Quinnesec schists, are unconformably beneath Upper Huronian sediments of this area. They also find evidence that the greenstones mapped in the Menominee monograph as equivalent to the Quinnesec schists (Keewatin) on the north side of the Menominee syncline are really intrusive into the Upper Huronian. The same is true of greenstones to the west along Brule River. The evidence is the increased metamorphism of the slates near the contact and the existence of occasional dikes and sharp contacts without coarse fragmental material. They conclude further that the greenstones of this area are in more limited areas than now mapped; that low-lying covered areas without exposure between greenstone knobs are probably underlain by slate rather than by greenstone.

LANE,[93] in 1905, discusses the Black River section of the Gogebic range across the Keweenawan series. Observations on the grain of the gabbro show it to be a deep-seated intrusive. Irving's estimate of the great thickness of the Keweenawan is confirmed. Evidence of unconformity is found between the upper Keweenawan and the lower Keweenawan. Pebbles in the conglomerate in the upper Keweenawan are derived from the lower Keweenawan. Some of these are deep-seated intrusives, and there must accordingly have been a considerable amount of erosion preceding the formation of the upper Keweenawan conglomerate. Abundant evidence of faulting across the series is observed.

[a] Van Hise, Charles R., and Bayley, W. S., The Menominee special folio: Geologic Atlas U. S., folio 62, U. S. Geol. Survey, 1900.

Wright,[94] in 1905, reports on progress in the mapping of the Keweenawan rocks of the Porcupine Mountain region of Michigan by the Michigan Geological Survey. A number of faults in the Keweenawan are described, most of them contemporaneous or subsequent to the deposition of the copper. Important changes in the mapping of this district, said to be necessary, are not described.

Lane,[95] in 1907, gives an outline account of the geology of Keweenawan Point, with special reference to the geological relations of the copper deposits. No essential modifications of the earlier writers are reported.

Lane and Seaman,[96] in 1907, present a geological section of Michigan, the lower part of which is as follows:

Partial geological section of Michigan.

System.	Series.	Formation.	Thickness (feet).	Character of rocks.
Ordovician.		St. Peter	0-75	Sandstone; white, water bearing, in hollows of Calciferous dolomite, but absent often.
		Calciferous	255-180	Buff and bluish dolomites, often sandy, with dolomitic white sandstones.
Cambrian or Primordial.	Neo-Cambrian (Saratogan; Potsdam; Upper Keweenawan, perhaps).	Lake Superior: Munising	200	Sandstone; white or light, water bearing.
		Lake Superior: Jacobsville redstone.	0-1,500+ (4,000?)	Sandstone; red and brown and striped with streaks of red clay shale, conglomeratic where it laps upon older formations.
		Lake Superior: Hiatus.[a]		
		Lake Superior: Freda	(900+)?	Sandstone; red, with some felsitic and basic débris, and salt water.
	Mio-Cambrian.	Nonesuch	350-600	Shales; dark, fissile beds, with dark basic fragments, and products of decomposition of lavas; copper bearing.
	Keweenawan (Lower Keweenawan, perhaps Eo-Cambrian).	Copper Harbor: Outer	1,000-3,500	Conglomerate; very heavy, red, with large rounded bowlders of all lower formations, including jaspilitic iron ores, agate amygdules, gabbro, aplites, etc.
		Copper Harbor: Lake Shore	1,800-400	Traps; basaltic lavas, and at least one (the "Middle") conglomerate.
		Copper Harbor: Great	2,200-340	Conglomerate; very heavy, like the Outer conglomerate.
		Eagle River	2,300-1,417	Group of basic lava flows, with frequent beds of sediment, Marvine's c.
		Ashbed	1,456-2,400± (50 sediment)	Group of basic lavas of the "ashbed" type with scoriaceous sediment and only 50 feet or so of conglomerate. Locally felsites.
		Central Mine	3,823-25,000? (480 sediment)	Group; mainly of lavas of the augitic ophite type, with infrequent sediments. At the top is the "Mesnard epidote," and just beneath it the heaviest flow, over 1,000 feet thick at times, known as the Greenstone. Under this is the Allouez conglomerate. Marvine's No. 15. No. 13 is the Calumet and Hecla conglomerate or lode. The Kearsarge lode is shortly above 9.
		Bohemian Range.	(?)-9,500+ (500 sediment)	Group; mainly of basic lavas but with intrusive and effusive felsites and coarse labradorite porphyrites; also intrusive diabase dikes and gabbro and gabbro aplites.

[a] The relation of the Freda to the Lake Superior sandstone is uncertain; probably they are one formation.

Partial geological section of Michigan—Continued.

System.	Series.	Formation.	Thickness (feet).	Character of rocks.
Huronian.	Animikean (Neo-Huronian).	Michigamme	1,000-4,000	Slates; black and graphitic, and graywacke slates, passing into graywacke arkoses, and quartzites; metamorphosed into staurolite, chiastolite, garnet, and other mica schists and phyllites.
		Bijiki	300-800	Iron formation or schist; slates with cherty carbonate and soft ore.
		Goodrich	0-400+	Quartzite; with conglomerate base, and above quartzite or red and green flags, also volcanic material.
	Mio-Huronian.	Negaunee	1,000±	Iron formation; cherty carbonates, altered to jaspilites, etc., with effusives and intrusives altering to hornblende schists and amphibolites.
		Siamo	600±	Slates; graywackes and arkoses and volcanics.
		Ajibik	700±	Quartzite.
	Eo-Huronian.	Wewe	300±	Slate; black largely.
		Kona	600±	Dolomite; with siliceous cherty and slaty (schistose) bands.
		Mesnard	250±	Quartzite; conglomerate and arkose, becoming a sericite schist or gneiss.
Laurentian.		Keewatin (Marenisean) = Laurentian.	1,000+	Greenstone schists, amphibolites, hornblende schists, sericite schists or crushed felsites, rarely ellipsoidal greenstones and slates and jaspilites, very largely cut by granites, the Laurentian, and numerous other classes of injections.

This succession is essentially the same as that of the later work of the United States Geological Survey in Michigan, but some of the names differ, the thicknesses and characters of the rocks are not in all cases the same, and there are differences in the major correlation. The principal points of difference are as follows:

The Archean or Basement Complex of the United States Geological Survey is here called Laurentian. Its subdivision into Laurentian and Keewatin is essentially the same. The Palmer gneiss of the Laurentian of the United States Geological Survey is here regarded as representing sheared phases of the lower part of the Huronian series, up to the Siamo slate.

The Upper, Middle, and Lower Huronian of the United States Geological Survey are here called Neo-Huronian, Mio-Huronian, and Eo-Huronian. They include the same formations. The Clarksburg volcanics, instead of being correlated with the Upper Huronian, are correlated with both the Middle and the Upper Huronian. All of the iron formation of the Upper Huronian is included in the Bijiki formation, which is regarded as more continuous than had been indicated in the work of the United States Geological Survey. The Bijiki schist has previously included only one of the members of the iron formation. The Michigamme slates and their equivalents are regarded as usually not over 1,000 to 2,000 feet thick, although on the Gogebic range they are apparently 4,000 feet thick. The United States Geological Survey figures have been 12,000 or 15,000 feet for the Gogebic section.

The Keweenawan series is regarded as representing the Lower and Middle Cambrian and not the upper part of the pre-Cambrian section. They are described as Cambrian beds disturbed by coeval volcanic activity and faulting, and seem comparable with inter-Keweenawan phenomena, while the Lake Superior sandstone and the Upper Keweenawan appear closely associated not merely lithologically, but stratigraphically. The thickness of the Keweenawan is not less than 15,000 feet and may be as much as 42,500 feet, a figure which may be reduced by initial dip and repetition by faulting to 29,000 feet. Sediments constitute not more than 15 per cent of the section. The Keweenawan is divided into groups as follows, with names and characteristics varying somewhat from those previously used:

(1) The Bohemian group, corresponding to Irving's groups 1 and 2.

(2) The Central Mine group, including the "Greenstone group," the "Phoenix Mine group," etc., but only a part of Pumpelly's "Portage Lake series," and just about that part included and well exposed in the workings of the Central mine on a cross fissure, exposing a good section, examined by Pumpelly and Hubbard, and more recently supplemented by diamond-drill cores on the same property (secs. 24, 25, 36, T. 58 N., R. 31 W.). This is a new name we would introduce and define as extending from the Bohemia conglomerate, Marvine's conglomerate 3 or 8, to the "St. Mary's epidote," a sediment, volcanic ash, just above the "Greenstone" and Marvine's conglomerate.

(3) The Ashbed group, including Marvine's *a* and *b* and Irving's 5 and 6.

(4) The Eagle River group, Marvine's *c*.

(5) The Copper Harbor conglomerates, including the Great and Outer conglomerates, which have been subdivided by Hubbard into three heavy conglomerates.

(6) The Nonesuch formation, same term as previously used.

The Neo-Cambrian or Potsdam or Lake Superior sandstone includes (1) the sandstones west of the Copper range, to which the new term Freda sandstone is applied, (2) the sandstones east of the Copper range, to which the term Jacobsville is applied, and (3) the sandstones in the bluffs back of Munising, to which the term Munising sandstone is applied. The relations of the Freda sandstone to the Lake Superior sandstone are uncertain, but they are regarded as probably one formation. The Freda sandstone had previously been called by Irving the Western sandstone, correlated with the Keweenawan, and regarded as unconformably below the Lake Superior sandstone. The Jacobsville and Munising sandstones were regarded by Irving as true Lake Superior or Potsdam sandstones.

The United States Geological Survey term Algonkian for the Huronian and Keweenawan series is not used.

Gordon and Lane,[97] in 1907, describe a geological section from Bessemer down Black River in Michigan. Keweenawan rocks are exposed to a minimum thickness of 60,000 feet, and the real thickness is a large fraction of this, even after making allowance for faulting, initial dip, and uncomformity. It seems probable that the full thickness exists in the center of the Lake Superior basin, but that around the margin of the basin, owing to erosion, denudation, and uplift, the bottom beds were never buried by any such thickness. The dip of the Keweenawan at the south end of the section is 78° and at the north end 20°, in part as a result of sinking of the Lake Superior basin contemporaneous with deposition, but possibly in part due to unconformity. A conglomerate below the base of the Nonesuch sandstone contains more than the usual number of jasper fragments from the Animikie formation and may possibly represent such a break, but if this break were present bowlders from the basic rocks making up the base of the series should be more numerous in the conglomerate. Many dip faults are found. Strike faults are not observed, but are believed to be present. From change in grain of the gabbro from the surface inward Lane argues that its initial temperature of crystallization was 1,850°. In a note on the pre-Keweenawan rocks Lane calls attention to the existence of basic tuffaceous slate, not certainly in place, in the area of the iron-bearing formation near Bessemer, possibly representing contemporaneous volcanic activity.

For fuller summaries of articles referring to the Michigan ore-bearing districts see Monographs V, XIX, XXVIII, XXXVI, and XLVI of the United States Geological Survey.

SECTION 2. NORTHERN WISCONSIN.

SUMMARY OF LITERATURE.

Owen,[98] in 1847, gives many details of the formations of the interior of the Chippewa land district and of the formation of Lake Superior. In the first district are seen many varieties of granite, syenite, greenstones, hornblende rock, gneiss, and mica slate. Magnesian and magnetic slates are capped unconformably by pebbly sandstones for nearly a mile along Black River. The red sandstone of Lake Superior on Raymonds Creek is estimated by Randall to be 10,000 feet in thickness.

Owen,[99] in 1847, finds the horizontal sandstone to overlap the crystalline and metamorphic formations at the southern portion of the Chippewa land district near the falls of the streams flowing into the Mississippi. The region to the north is based upon crystalline, granitic, and other intrusive rocks. North of the summit levels of the Chippewa land district the peculiar formations of the Lake Superior country commence. These are red sandstones, marls, and conglomerates, occasionally penetrated by intrusive ranges of hornblende, greenstone, trap, and amygdaloid similar in their general aspect to the contemporaneous ranges of igneous rocks which occur in the mining district of Michigan. Besides this trap formation there is an entirely distinct trap system, in immediate juxtaposition with which strata have been discovered which are as old as if not older than the *Lingula* beds of the Potsdam sandstone of New York.

WHITTLESEY,[100] in 1852, gives geological descriptions of part of Wisconsin south of Lake Superior. Passing from the lake southerly four great classes of rocks are seen in each section: (1) Sedimentary, including red sandstone, black slate, and conglomerate. (2) Trappose rocks, or those of volcanic origin, including amygdaloid, greenstone, augitic, hornblendic, and feldspathic rocks, embracing syenites and granites of the same age. (3) Metamorphosed rocks, including hornblende slates, iron slates, black slates, talcose slates, and slaty quartz. (4) Granitic, including syenite and granite. The granites and syenites of the interior are the most ancient rocks of the district. Since the protrusion of these granitic masses many changes have occurred. The sandstone of Lake Superior must have been deposited subsequent to the granites of the Wisconsin, Chippewa, and Montreal rivers, for that period has been one of long and intense igneous action in which the trap, hornblendic, and greenstone masses have been ejected, and also with them protrusions of recent granites and syenite. The metamorphic slates have been elevated during these convulsions, and the sedimentary rocks thrust far northward and tilted up at high angles. The old granites and syenites have been rent with fluid matter, such as quartz and hornblende. The northern part of the Penokee range shows evidence of four formations of trappose rocks, which fill a geological epoch of no great duration between the area of the red sandstone deposits and the metamorphic uplifts. There are cases where the trap, instead of being forced across the strata, has spread out between the beds, forming alternate strata of trap and sandstone without any visible conglomerate.

PERCIVAL, in 1856, discusses the geology of this district. See summary in Chapter XII, section 1, Baraboo, page 717.

LAPHAM,[101] in 1860, describes the Penokee iron range. Here is found a mountain mass of iron ore in an ancient chloritic slate which rests upon a light-colored quartz rock. Above and north of the ore the slate is hardened, probably by some volcanic agency. The whole series dips to the north.

HALL (JAMES),[102] in 1861, describes the quartzite ranges of northern Wisconsin, and particularly those of Spirit Lake, as having been original stratified sandstones which have undergone subsequent metamorphism. These rocks are folded with their axes lying in an east-west direction and had become uplifted and metamorphosed before the commencement of Potsdam time. In the quartzites in two or three localities are found beds of conglomerates. These metamorphic masses are in all probability the extension of the Huronian formation of Canada.

HALL (JAMES),[103] in 1862, describes the central and northern areas of Wisconsin as consisting of the Azoic rocks. These are hard and crystalline, and in many places are destitute of lines of bedding, though they are in reality as regularly stratified as the more modern formations. Notwithstanding their crystalline character, the alternation of beds of different texture indicates their original different mechanical conditions as clearly as in any of the unaltered strata. They were deposited precisely as clay, sand, and limestone strata of more recent geological periods were, and owe their present character to metamorphism. These rocks are granitic, syenitic, gneissoid, or hornblendic. In the southern part of the area of the crystalline rocks are numerous elevations of them appearing within the limits of the succeeding stratified rocks; so we know that the latter are of later date. North of the Azoic rocks is the range of trap, conglomerate, and sandstone bordering Lake Superior and known as the copper region. The quartzite ranges of Baraboo and Necedah hold the same position relative to the Potsdam sandstone as does the Huronian system of the Canadian survey.

WHITTLESEY,[104] in 1863, describes the copper-bearing strata of Keweenaw Point as extending southward across the boundary of Michigan into Wisconsin, a distance of 160 miles. The order of rocks along the line is everywhere the same. Beyond the copper range, which is nearer to Lake Superior, is a second range known as the iron range, and to this the name Pewabik was applied, although by a misprint it was transformed to Penokee.

Passing from Lake Superior to south of the iron range, the structure in descending order is as follows: Formation No. 1, Potsdam sandstone, consisting of sandstones, conglomerates, black slates, and alternations of trap and sandstone; No. 2, trappose, in two members; No. 3, hornblendic; No. 4, quartz, with slaty layers, separated into two members by a bed of magnetic iron and iron slate; No. 5, granites and syenites of central Wisconsin. This system is everywhere stratified and conformable throughout. On Bad and Montreal rivers are found no masses of crystalline limestone.

MURRISH, in 1873, describes Azoic rocks at Grand Rapids, on the Wisconsin River, similar to those on Black River. See summary in Chapter XII, section 1, page 724.

IRVING,[105] in 1874, describes as occurring in northern Wisconsin four distinct groups of rocks—the Laurentian, Huronian, Copper-bearing, and Lower Silurian. The Laurentian consists of granites, gneisses, and syenites for the most part, although there may be various schist beds present. The Huronian rocks consist of siliceous schists, quartz rock, and black slates, magnetic and specular schists and slates, metamorphic diorite, and diorite schists. Its lowest portion is simple siliceous schist with some granular white quartz, gray quartzite, and black slate; the central portion consists of magnetic and specular slates and schists in which all the ores are found, and the highest and northernmost portion consists of diorites, diorite slates, diorite schists, and quartz slates. The Copper-bearing series is next north of and immediately overlies the Huronian, and is of enormous thickness, never less than 4 miles. The lower portions of the group are probably in part of igneous origin, but the upper portions are beyond all doubt exclusively the results of sedimentation. The group consists of shales, sandstones, conglomerates, amygdaloids, and traps. The sedimentary series do not altogether overlie the trappean beds, but near their junction are directly and unmistakably interstratified with them. The Silurian rocks in Ashland County are in a horizontal position in a trough between two lines of highly tilted beds of the Copper-bearing series. At one place the horizontal sandstone is found within a few hundred feet of the copper-bearing trap and within 2 miles of vertical sandstones of the same group.

In Douglas County the horizontal sandstone is traceable to within a short distance of the trap, and sometimes to actual contact, the trap, wherever observable, dipping southward and having no tilted sandstones and conglomerates associated with it. As the Huronian and Copper-bearing series are in apparent conformity it is concluded that they were once spread out horizontally one over the other, and owe their present highly tilted position to one and the same disturbance; and that subsequently, after a long period of erosion, the horizontal Silurian sandstones were laid down over and against the upturned edges of the Copper-bearing series; and that hence the Copper-bearing series is more nearly allied to the Archean than to the Silurian rocks. One fact is, however, difficult of explanation on this hypothesis. In Douglas County at several places the horizontal sandstones, when traced to their junction with the southward-dipping trap, present a remarkable change; the horizontal layers are suddenly seen to change from their ordinary position to a confused mass of broken layers, dipping in every conceivable direction and increasing in confusion as the trap is approached, until finally the whole changes to a confused breccia of mingled trap and sandstone fragments. It is suggested that this appearance is due to the movement of the solid trap northward against the sandstone since the deposition of the latter rock. The great Lake Superior syncline of Copper-bearing rocks is found to extend west into northern Wisconsin.

Brooks (T. B.), in 1876, discusses the Huronian rocks south of Lake Superior, including the Penokee series. See summary in Chapter III, section 1, Michigan, pages 126–128.

Sweet,[106] in 1876, describes the junction of the Laurentian and Huronian rocks on Bad River. Here, at the base of the Huronian series, is a siliceous marble dipping 66° N., while 100 feet to the south is a ledge of gneissoid granite showing a well-defined dip of 77° S. There can be no doubt of the unconformity of these formations. The Penokee series is found to be about 5,000 feet thick, to be everywhere conformable, and to dip about 66° N.

On the Chippewa is found a quartzite which has a layer the lowest stratum of which is a reddish metamorphic conglomerate having a thickness of 300 feet. The pebbles of this conglomerate are either jasper or amorphous quartz. The conglomerate and quartzite are distinctly and heavily bedded. South of this quartzite are syenitic granites which are assumed to be of Laurentian age, and the quartzites and conglomerates are assumed to overlie them unconformably. A short distance north of the mouth of Snake River cupriferous melaphyres and amygdaloids are overlain by horizontal beds of light-colored Potsdam sandstone, while a few miles to the north conglomerates and shales conformably overlie the cupriferous strata. The conglomerate is heavily bedded, but does not cover the melaphyres and amygdaloids at all points, appearing to fill pockets and depressions in them rather than being interstratified. At St. Croix Falls on St. Croix River, Potsdam sandstone containing fossils are found in a horizontal position within a few feet of the cupriferous rocks. Depressions and pockets in the surface of the cupriferous rocks are filled with horizontal layers of the sandstone, and detritus from the crystalline rocks are found in its layers. The Lake Superior syncline is traced westward across Wisconsin and enters Minnesota. It is, then, more than 300 miles in length and from 30 to 50 miles in width.

Irving,[107] in 1877, summarizes the facts proved as to the older rock series of Wisconsin. There are here four series: The oldest are (1) gneisses and granites with other rocks; these are overlain unconformably by (2) a series of quartzites, schists, diorites, etc., with some gneiss and granite; these in turn are overlain—probably also unconformably, but this is not certainly proved—by (3) the Copper series, which includes greenstones and melaphyres and also great thicknesses of interstratified sandstone, melaphyres, amygdaloids, and shales, the whole having a thickness of several miles; these finally are unconformably covered by (4) a series of unaltered horizontal sandstone including numerous fossils, many of which are closely allied to those of the Potsdam sandstone of New York, and all of which have a marked Primordial aspect. To the Laurentian and Huronian systems of Canada are referred (1) and (2) because they bear the same relations to one another and to the Copper series that these systems do.

The exact junction between the Potsdam sandstone and the Huronian quartzite is seen at numerous places. The Potsdam, containing fossils and numerous fragments from the older rocks, lies upon and wedged in between the tilted ledges of the Huronian. Exactly similar unconformity is to be seen at the Dalles of the St. Croix between the Potsdam and the Copper series.

WIGHT,[108] in 1877, describes the horizontal Potsdam sandstone as resting on the uneven and tilted surface of the underlying igneous or crystalline rocks at St. Croix Falls. The sandstone contains numerous well-preserved fossils, even where almost in contact with the trap. At Pine Island, in Kettle River, the Superior red sandstone contains abundant fragments of the adjacent trap, forming a brecciated conglomerate kindred to the conglomerate which extends from Keweenaw Point along the northern base of the Porcupine and Penokee mountains. Everywhere this conglomerate is composed of fragments of the more elevated Huronian or trap ridges. The Superior red sandstone, wherever it borders the trap ridges, shows that it has been tilted, broken up, or crushed. It appears that the trap, whether erupted or upheaved convulsively or slowly, encountered this formation in its ascent. On the contrary, the Potsdam sandstone everywhere rests in a horizontal, undisturbed position on the bedding of the trap. Either the Superior red sandstone is older than the Potsdam or the trap rocks in conjunction with the Superior red sandstone are younger than those in conjunction with the Potsdam.

IRVING,[109] in 1877, describes the Archean rocks which cover all of Marathon, most of Wood, and much of Clark, Jackson, and Portage counties, in Wisconsin. The Laurentian is a great mass of crystalline rocks—granite, gneiss, chloritic, micaceous, and hornblendic schists—which are folded and eroded so as to offer the greatest obstacles to their detailed study. On the south side of the Laurentian core, on Black River, and in isolated masses, are ferruginous schists, quartzites, and quartz porphyries, which are probably Huronian. The presence of these rocks on the south, of the quartzites of Chippewa and Barron counties on the west, and of the Huronian rocks of the Penokee range on the north leads to the suggestion that the Huronian rocks entirely surround the Laurentian core of northern Wisconsin. The line of junction between the Archean area and the Potsdam formation to the south is exceedingly irregular. The latter always rests in a horizontal position upon the crystalline formations with the most marked unconformity, the exact contacts being found at several places. The most abundant of the crystalline rocks is gneiss, and the original bedded condition of the whole series is evident, not only from the prevailing gneissoid and schistose character, but also from the existence of distinct bedding planes, which can generally, even in the granitoid kinds of rocks, be readily made out. The processes of metamorphism and disturbance have been carried to the last extreme, as shown by the highly crystalline character of the rocks and the fact that the gneiss grades into granite, as well as by the greatly contorted condition of the gneiss laminæ and the close folding of the whole series. While the series as a whole is bedded, distinctly intrusive granite occurs, as shown by the way in which it joins and penetrates the bedded rocks. The main area of the crystalline rocks certainly belongs to the Laurentian; only a small area on the south of the district is doubtfully Huronian.

Very numerous details are given as to particular localities, showing the manner of occurrence and the relations of the different varieties of rocks and the unconformities which exist between them and the Silurian. On Mosinee and Rib hills are large exposures of quartzite. At Black River Falls the regularly bedded succession of highly tilted strata of many members consists in large part of regularly laminated schistose rocks, such as ferruginous quartz schist and magnesian schist or slate, having together an approximate thickness of at least 5,000 feet. Gneiss and granite are also found here.

Isolated from the main Archean area are numerous exposures of crystalline rocks which protrude in moundlike forms from beneath the horizontal strata. The largest of these are the quartzite ranges of Baraboo. About many of these areas is found horizontal sandstone lying immediately against the tilted crystalline rocks and carrying pebbles and bowlders derived from them, proving that they are all of greater antiquity than the surrounding sandstone layers. These relations are particularly well shown in the Baraboo quartzite ranges. Aside from these ranges, the more important areas are the Marcellon, Observatory Hill, Moundville, Seneca (Pine Bluff), Marquette, and Berlin quartz porphyries, the Montello and Marion granites, and the Necedah quartzite.

IRVING,[110] in 1878, describes the siliceous slate at Potato River, which is one of the lower members of the Huronian, as in contact with the chloritic gneiss of the Laurentian. The slate inclines at a high angle to the north, while the gneiss layers dip to the south and strike in a direction oblique to that of the slate layers.

CHAMBERLIN,[111] in 1878, describes the exact junction between the Laurentian and Huronian series on the Gogogashugun, in the Penokee district. The Laurentian member consists of a peculiar gneissoid rock, like that which occupies a similar relation at Penokee Gap. The Huronian lies in absolute contact with this. Its siliceous material at the time of its deposition so insinuated itself into the irregularities of the surfaces of the gneiss that the two formations are interlocked, and of a hand specimen that was obtained one portion is Laurentian gneiss and the other Huronian schist, the two being unconformable. The Huronian siliceous schists are overlain by beds of white and red quartzite, and these graduate into alternating layers of quartzite and iron ore. The iron-ore horizon is here hematitic and soft, but is the equivalent of the hard magnetic horizon to the west. In this part of the belt are presented the greatest probabilities of the existence of workable ore.

Wright, in 1879, discusses the Laurentian series south of Lake Superior, including those of Penokee Gap. See summary in Chapter III, section 1, Michigan, page 128.

Irving,[112] in 1880, gives a comprehensive account of the general structure of northern Wisconsin. Here are found four great systems—the Laurentian, Huronian, Keweenawan, and Lower Silurian—which are unconformable with one another. The rocks of the crystalline nucleus are correlated with the Laurentian of Canada because they sustain the same structural relations to the Huronian, Keweenawan, and Lower Silurian as does the typical Laurentian of Canada, and because they have the same general lithological peculiarities. There can be no reasonable doubt that they are directly continuous with the Canada Laurentian. The prevailing rocks are granite and gneiss. These rocks are greatly folded and certainly have an enormous thickness. It is evident that they are of true sedimentary origin.

The granites are generally without distinct bedding, but no eruptive granite recognizable as such has been observed.

Lying immediately against the Laurentian, and sharply defined from it, extending from Montreal River to Lake Numakagon, is a belt of schistose rocks which are beyond question the westward extension of the iron-bearing series of the Upper Peninsula of Michigan. This belt has an aggregate thickness of strata of 13,000 feet. The subdivisions, beginning below, are (1) crystalline limestone; (2) quartz schist and argillitic mica schist; (3) tremolitic magnetite schists, magnetic and specular quartzites, and lean magnetic and specular ores; (4) alternations of black mica slate with diorite and schistose quartzites; (5) mica schists with coarse intrusive granite. These major divisions are again subdivided at Penokee Gap and vicinity. The system always dips north, usually at a high angle, and the strikes are oblique to the underlying Laurentian gneiss, proving the unconformity of the two systems, the actual contact of which can be seen in several places. These rocks are regarded as the equivalent of the Huronian of Canada, because they are the direct continuation of the iron-bearing system of Marquette, because the grand divisions of the Bad River and Marquette system are similar, because they show the same relations to the Laurentian and Keweenawan systems as are found in the Huronian of Canada, i. e., newer than the former and older than the latter, and because the Marquette and Menominee sediments are in unconformable contact with the Lower Silurian sandstone.

The Keweenawan system is a distinctly stratified one, in large measure made up of eruptive rocks in the form of flows. These constitute the lower 10,000 feet of the system, and above these are found the detrital rocks, increasing in frequency, until they wholly exclude the igneous rocks in the upper 15,000 feet. The eruptives of the system are chiefly diabase, melaphyre, and gabbro. The succession on Montreal River is (1) chiefly diabase and diabase amygdaloid, with little satisfactory appearance of bedding and having a width of about 33,000 feet; (2) alternations of (1) with red sandstone and shale, 1,200 feet; (3) bowlder conglomerate, 1,200 feet; (4) alternations of shale and quartzless sandstone, 350 feet; (5) red sandstone and shale, 12,000 feet. If the series is regarded as a continuous one it is at least 50,000 feet thick. There are two prominent belts of the Keweenaw rocks in northern Wisconsin lying parallel to each other and having between them a synclinal depression which is occupied by Chequamegon Bay. The Keweenawan system is evidently newer than the Penokee system. That the two systems are actually nonconformable in these regions is not evident, for in sections the dip in passing from one to the other is generally nearly the same. That there is a real unconformity is indicated by the facts (1) that in passing westward from Penokee Gap the uppermost beds of the Huronian are gradually cut off by the gabbro that forms the base of the Keweenaw series; (2) that there is not an absolute conformity in dip between the Huronian and the Keweenawan rocks; (3) that west of Lake Numakagon the diabases and other eruptive rocks of the Keweenaw series appear completely to cover the Huronian.

The Lake Superior sandstone is always in a horizontal position and is more highly siliceous than the sandstones of the Keweenawan system. At St. Louis River it overlies unconformably the Huronian schists. In Douglas County are several junctions of the sandstone with the Keweenawan rocks. Here the horizontal sandstones in approaching the eruptive rocks of the Keweenawan system are found to be brecciated and tilted, the original lines of deposition being sometimes entirely obliterated. These peculiar appearances are regarded as due in part to the naturally confused mode of deposition on the cliffy shore in which the sandstone was originally deposited; but a slight movement of the deep-seated crystalline rocks against the more superficial sandstones would also account for many of the phenomena. That the sandstone formation rests unconformably upon the Keweenawan system is further shown by the fact that in the Dalles of the St. Croix the horizontal sandstone and shales, with characteristic Primordial fossils, lie upon the irregular and eroded surface of a Keweenawan melaphyre.

The Penokee series is compared with the Marquette Huronian and there is found to be a general likeness in the rock succession in the two regions. Very numerous detailed sections and outcrops at particular localities are fully described and mapped.

WRIGHT,[113] in 1880, describes the Huronian series west of Penokee Gap. The succession here found is limestone, chloro-siliceous schists, quartzites, magnetitic schists, Keweenawan; the magnetitic schists being occasionally interstratified with greenstone. At Penokee Gap is found a dolomitic limestone overlain with quartzite and chloro-siliceous schists, which rests unconformably upon the Laurentian rocks. The Huronian rocks here have a dip of 66° N., while the Laurentian rocks have a southern inclination of 65° to 80°. West of Numakagon Lake the magnetic attractions are found to cease and the Copper-bearing series and granite belonging to the Laurentian are found in direct contact. This appearance is regarded as being due to the covering up of the Lower Huronian by the Copper-bearing rocks.

SWEET,[114] in 1880, describes the geology of the western Lake Superior district. The geological formations here found comprise the Laurentian, Huronian, and Keweenawan systems. The Keweenawan rocks are found in a great syncline. In northern Wisconsin, below the Keweenawan, no southward-dipping rocks are found that are referred to the Huronian, but in Minnesota, along St. Louis River, are strata which occupy a position inferior to the Keweenawan series, are lithologically like the slates of Ashland County, and are cut by numerous dikes in lithological character precisely like the rock at the base of the Copper-bearing series. Hence they are regarded as Huronian. The Copper-bearing strata consist of a detrital upper portion of sandstones, conglomerates, and breccias, having a maximum thickness of 9,000 feet, and of eruptive strata, consisting of melaphyre, diabase, porphyry, gabbro, etc., having an apparent maximum thickness of more than 36,000 feet. The quartzites, siliceous schists, and chloritic slates along St. Louis River, referred to the Huronian, are many thousand feet thick. Upon the St. Louis slates at one place the Lake Superior red sandstone and conglomerate repose unconformably. The Keweenawan eruptive rocks are bedded. They have a very persistent and rather uniform dip and strike in any given locality. The layers are seldom less than a foot or two in thickness and are more often many feet thick, so as to give an exposure an unstratified appearance. On one side of each layer is a precipitous and somewhat jagged ridge, owing to the exposure of the edge of the layers, while on the other side the soil descends with the inclination of the bedding.

As to the age of the Copper-bearing series, it can only be said that they are older than the Lake Superior red sandstones, for when the latter is conglomeratic the pebbles are almost invariably derived from the Keweenaw series. Also the perfectly horizontal sandstones approach in that condition within 15 or 20 feet of the dipping crystalline rocks, and from this it is assumed that they unconformably overlie them. At Black River Falls on lower Black River, at the gorge of Copper Creek, and along the west bank of Middle River the horizontal sandstones are found, in approaching the eruptives of the Copper-bearing series, to become uptilted, brecciated, and in some cases conglomeratic, and sometimes wholly lose their structure. The eruptives in all these cases dip away from the uptilted sedimentary rocks.

Chamberlin and Strong,[115] in 1880, describe the geology of the upper St. Croix district. The Keweenaw series is composed of two classes of rocks—massive crystalline beds which owe their origin to the succession of outflows of molten rocks, and conglomerates, sandstones, and shales derived from the wear of these igneous rocks and from the older formations. They are in part interstratified with the igneous rocks and in part overlie them. The eruptives are mainly diabase and diabase amygdaloid, although melaphyre is found. The Keweenawan beds were deposited in essentially a horizontal condition, were bent into their present troughlike form and eroded, and upon their upturned edges was deposited the Potsdam sandstone. This is shown by the fact that at St. Croix Falls the horizontally stratified sandstone is found within a few feet of an exposure of highly inclined Keweenawan melaphyre containing numerous fragments derived from it. This sandstone has characteristic Potsdam fossils. At one place near the falls, in a small gorge, the Potsdam is found directly superimposed upon the melaphyre. The melaphyre is cut by vertical planes of division which are fairly smooth and uniform; but there is another persistent set which is much less smooth, though persistent and constant in direction. These planes are usually in detail slightly uneven and undulatory and are separated by several feet. They are believed to represent the dip of the igneous beds. It is upon the persistence of these inclined beds, taken in connection with their parallel lithological habit, that the determinations of dip are based. Outside of the district the northward-dipping diabase is found on one side of Numakagon River, while on the other is seen the Laurentian granite.

Brooks,[116] in 1880, gives the geology of the Menominee iron region. The Lower Silurian sandstone is found capping the older rocks near Lake Eliza. The Laurentian granite, gneiss, and crystalline schist series is not subdivided. No limestones, dolomitic marbles, conglomerates, calcareous or arenaceous chloritic schists are considered as belonging to the Laurentian system. It is not certain whether this series occurs in Wisconsin within the area surveyed.

The Huronian series is divided into lower, middle, and upper divisions. The lower division comprises the lower quartzite, of great thickness, the great marble formation, and the great iron-ore horizon containing magnetitic, hematitic, and jaspery schists, as well as deposits of iron. The Middle Huronian comprises quartzites, clay slates, and obscure soft schists. The Upper Huronian includes mica schists, gneisses, and granite, the last of which may possibly be eruptive, but is the topmost member of the Huronian succession. Interstratified with the Huronian are diorites, diabases, gabbros and greenstones, and greenstone schists, which are believed to be conformable beds of metamorphosed sediments. They are never found in the form of dikes. The thickness of the Huronian in the Menominee is not far from 10,000 to 15,000 feet. There is great difficulty in ascertaining exactly the thickness on account of the sharp folds, where thick beds double back upon themselves. This especially affects the quartzites, clay slates, and greenstones. The relative proportions of the different kinds of rocks of the Huronian and a correlation of the successions in various districts of the Menominee are given, and the twenty members (including the upper granite) are correlated in detail with successions north of Lake Huron and in the Marquette, Gogebic, Penokee, and central Wisconsin regions. The resemblances between the Marquette, Menominee, Sunday Lake, and Penokee series are so numerous as to point unmistakably to their having been formed in one basin under essentially like conditions. Detailed sections and maps of the rock exposures are given at numerous points. The youngest Huronian member, the granite, has a wide extent. While this is true, granite dikes are rare in the Menominee Huronian and have never been observed in the Marquette series. No rocks affording the slightest suggestion of conglomeratic structure have been found in the Laurentian, its rocks everywhere being much metamorphosed, and in many places so much as to destroy all traces of bedding. Underlying the quartzite at Sturgeon River Falls is a schist conglomerate which has numerous pebbles of what appear to be granite and gneiss from the adjacent Laurentian. In the Pine and Poplar River regions is found conglomeratic quartz schist containing micaceous iron and magnetite. In the Commonwealth section are included quartz schists which are conglomeratic, containing pebbles of white quartz and jasper. There are also found in the upper beds of the Huronian conglomeratic micaceous quartz schists. At various places granites and gneisses overlie conformably the younger Huronian schists, into which they send dikes. As the evidence of bedding is rare, it is possible that toward the end of the Huronian period there was a great eruptive overflow of these rocks. Cutting the Laurentian rocks in all directions are dikelike masses of granite and greenstone. The abundant greenstone dikes of the Laurentian are much more common than the Huronian, and resemble the Huronian bedded diorites. It is suggested that these dikes have afforded the material for the greenstones and related schists of the Huronian. May not also considerable of the magnetite come from the same source?

WRIGHT,[117] in 1880, in describing the western and southern extension of the Menominee range, states there can be no doubt that the granite is younger than the Lower Huronian. This latter dips under the former, and veins of the former penetrate the latter, but whether it belongs to the Lower Huronian is an open question.

STRONG, SWEET, BROTHERTON, and CHAMBERLIN,[118] in 1882, further describe the quartzites of Barren and Chippewa counties. They are found in several localities to contain beds of conglomerate, to have not infrequently distinct bedding, and to contain locally beds of pipestone.

KING,[119] in 1882, describes the rocks of the upper Flambeau Valley. They are found to be mainly granite, gneiss, hornblende schist, and mica schist, and are all referred to the Laurentian.

IRVING and VAN HISE,[120] in 1882, describe the crystalline rocks of the Wisconsin Valley. The crystalline rocks here found are a great series of schistose gneisses. Alternating with these are finer grained and more highly lamellar schists. Intersecting the gneiss are dikes of various basic rocks, while structureless masses of granite, presumably intrusive, are also found. In the vicinity of Wausau are argillaceous quartz schists and quartzites, which on lithological ground may be referred to the Huronian, although of the structural relations of these rocks with the Laurentian gneisses nothing is known.

CHAMBERLIN,[121] in 1883, gives a systematic account of the geology of Wisconsin. The rocks of Laurentian age are mainly of the granitic type, consisting largely of granites, gneisses, syenites, and hornblendic, micaceous, and chloritic schists, with allied rocks. These are associated with igneous diabase, diorites, and similar rocks. This series is regarded as a sedimentary accumulation, on the grounds (1) of foliation and stratification; (2) of the alternating bands of varying chemical constitution; (3) of the verging of one kind of rock into another laterally; and (4) of the presence of kinds of rocks not known to be produced by igneous agencies. The thickness of these sediments is enormous. An estimate of 30,000 feet is probably not too great.

The calcareous and carbonaceous beds of the Laurentian of Canada, as well as the Archean limestones and iron-ore beds of New York, are considered to be Huronian rather than Laurentian, and if this is so there is present in the Laurentian no positive evidence of life, although future investigations may reveal evidences of organic beings. The development of life in the Primordial is so abundant as to lead to the conclusion that for its evolution to this degree of perfection a vast prior period of time was required, which probably would carry the life well down into the Laurentian series. It is further suggested that the abundance of alkaline rocks in the Laurentian may be due to the effects of life in the Laurentian ocean.

Between the Laurentian and Huronian periods the Laurentian beds were closely folded; the sediments were changed by metamorphism to a thoroughly crystalline condition, and the series was profoundly eroded. About the thus formed Laurentian isles was deposited the Huronian. This comprises the Penokee series, the Menominee series, the Baraboo quartzites, the quartz porphyries of central Wisconsin, the quartzites and catlinite of Barron and Chippewa counties, and the iron-bearing series of Black River Falls. These series consist for the most part of limestones, slates, sometimes heavily carbonaceous, quartzites, hematitic and magnetitic schists, mica schists, and diorites. The presence of limestones, carbonaceous shales, and iron ore is taken as the evidence of life. After the deposition of the Huronian it was upheaved, metamorphosed, and eroded before the beginning of Keweenawan time, although the unconformity between the two series in Wisconsin is but slight and the above changes were only partially accomplished when the Keweenawan eruptions began. The metamorphism was less in degree than that which has affected the Laurentian strata, but is more intense than that which the Keweenawan series has suffered. It was not in general sufficient to obliterate the original grains and pebbles, nor to destroy ripple and rill marks. In the Huronian strata are igneous beds and dikes of gabbros, diabases, and diorites, the age of which is not certain. They may be, so far as yet known, in part contemporaneous and in part subsequent, or wholly the one or the other.

The rocks of the Keweenawan period consist of interstratified igneous and sedimentary beds; the former mainly diabases, with some gabbros, melaphyres, and porphyries; the latter conglomerates, sandstones, and shales derived mainly from the igneous rocks. The maximum thickness is about 45,000 feet, of which the upper 15,000 feet is sedimentary. The bottom of the Lake Superior basin was gradually subsiding during the time of the formation of these beds. While tilted, they are not contorted or metamorphosed. There is in this period no direct evidence of the existence of life. Over the great conglomerate of the Penokee and Porcupine mountain regions is a black shale that simulates the shales of later ages formed in association with life. After the close of the Keweenawan period, before the Potsdam sedimentation began, there was a period of erosion. How great this interval was has not yet been determined;

quite possibly the lower Cambrian formations of Great Britain and Bohemia bridge the entire interval.

Irving,[122] in 1883, gives a systematic account of the lithology of Wisconsin. Among the eruptive rocks are placed diabase, melaphyre, gabbro, norite, diorite, peridotite, syenite, porphyry, and granite. Among the schistose rocks are gneiss, mica schist, hydromica schist, actinolite schist, tremolite schist, hornblende schist, augite schist, chlorite schist, talc schist, magnetite schist, hematite schist, quartz schist, quartzite in part, chert schist, and jasper schist. Among the half fragmental rocks are quartzite, clay slate, and novaculite. The explanation of the origin of gneiss or lamellar granite by metamorphism, the structure being regarded as residual sedimentation, is not satisfactory. Many rocks which have been called metamorphic are placed as eruptive, and it seems not improbable that the same origin is to be attributed to some rocks with a strongly developed schistose structure. The hornblende schists are regarded as altered forms of augite schists.

Wooster,[123] in 1884, describes, on St. Croix River near Osceola Mills, the Potsdam sandstone carrying fossils, which grades down into a conglomerate containing pebbles from the Keweenawan, Laurentian, and Huronian series. The sandstone and conglomerate rest unconformably upon the underlying Keweenawan rocks.

Irving and Van Hise, in 1890 and 1892, give a detailed description of the Penokee-Gogebic series of Michigan and Wisconsin. See summary in Chapter III, section 1, Michigan, pages 140–144.

Van Hise, in 1896, describes a base-level in north-central Wisconsin and Keweenaw Point. See summary in Chapter III, section 1, Michigan, page 154.

Berkey,[124] in 1897 and 1898, describes and maps the geology of the St. Croix Dalles of Wisconsin and Minnesota. Keweenawan eruptives are exposed at numerous localities, and particularly along the river, where, by their erosion, they have formed the dalles of St. Croix River. The dip is about 15° S., which would give a thickness to the rocks in sight of 4,000 feet. At several localities the Basal sandstone unconformably overlies the Keweenawan eruptives with visible contacts, the Basal sandstone including the sandstone and shale series between the Keweenawan and the St. Lawrence shales.

Grant,[125] in 1900, describes and maps the Upper and Lower Keweenawan copper-bearing rocks of Douglas County, Wis. The Lower Keweenawan appears in a broad belt running northeast-southwest across the county, widening toward the southwest, and in a small belt cutting through the southeast corner of the county. It consists mainly of basic lava flows, associated with which, in the area in the southeast corner of the county, are a few beds of conglomerate composed of débris of the closely adjacent underlying rocks. The Upper Keweenawan appears in a broad belt in the southeastern part of the county between the two belts of Lower Keweenawan rocks. It is a series of conglomerates, sandstones, and shales. In a belt north of the northern belt of Lower Keweenawan rocks, extending from these rocks to the shore of Lake Superior, is the Lake Superior sandstone (Cambrian). This is either flat lying or dips slightly toward Lake Superior. The junction of the sandstone with the Lower Keweenawan is marked by a fault, along which the Lake Superior sandstone has been depressed, in some places probably as much as several hundred feet.

The Upper and Lower Keweenawan belts form a syncline, the axis of which runs northeast-southwest through the center of the tract underlain by Upper Keweenawan rocks.

While the Keweenawan rocks of this area are the same in kind and in age as are the productive copper-bearing rocks of Keweenaw Point, the probable unproductive character of the Douglas County rocks is intimated.

WEIDMAN,[126] in 1903, describes a pre-Potsdam peneplain of the pre-Cambrian of north-central Wisconsin and shows that it slopes gradually to the south, where it is covered by Paleozoic sediments. Several monadnocks stand above the pre-Potsdam peneplain. Extensive clay deposits near the contact of the Paleozoic and the pre-Cambrian are believed to have developed during the pre-Potsdam base-leveling.

BURLING,[127] in 1905, maps and describes the quartzite of Barron County. There is a prevailing westward dip, indicating a thickness of quartzite of 5,000 feet, if folding and faulting do not duplicate the series.

WEIDMAN,[128] in 1905, maps and describes a pre-Cambrian area of north-central Wisconsin containing about 7,200 square miles and including the counties of Marathon, Portage, Wood, Clark, Taylor, Lincoln, and adjacent parts of Gates, Price, and Langlade. From 90 to 95 per cent of the pre-Cambrian rocks of this area are of igneous origin.

The rocks believed to be the oldest consist of a complex mixture of rocks such as contorted and crumpled granite gneiss, diorite gneiss, granite schist, syenite schist, and diorite schist. The gneisses and schists form a belt or group which can be fairly well outlined, extending from the vicinity of Stevens Point and Grand Rapids in a northwesterly direction through Neillsville. This group of rocks is referred to as the basal group. Its various members are closely interwoven and intermingled with one another, and have been subjected to extensive folding and metamorphism. The zone or belt in which this group is largely comprised lies between areas of later igneous and sedimentary rock to the north and to the south, and hence appears to have the position of the arch of an anticline. This basal group is intruded by later formations of rhyolite, diorite, and granite. Sedimentary rocks have not been found in contact with this group.

The next group of rocks is of sedimentary origin and consists of quartzite, slate, and graywacke. These formations include the quartzite of Rib Hill and vicinity, the quartzite of Powers Bluff and in the vicinity of Junction and Rudolph, a wide belt of slate in northwestern Marathon County, and graywackes in the vicinity of Wausau. These formations are almost entirely of fragmental origin and only rarely contain phases of carbonaceous, calcareous, and ferruginous deposits. The floor upon which this group of sediments is deposited can not be definitely determined, for in all observed cases the contacts are either with later intrusive igneous rocks or with later overlying conglomerate. The quartzites are throughout extremely metamorphosed and to all appearances completely recrystallized. The slates and graywackes do not reveal as much metamorphism as the quartzite, although in places rocks presumably belonging with the slate formation have been changed to schists bearing staurolite, cordierite, and garnet. These sedimentary formations appear to bear the relation of great fragmentary masses intersected and surrounded by later igneous intrusives. They constitute the lower or older sedimentaries of this area.

The next younger group of rocks is of igneous origin. This group forms about 75 per cent of the rocks of the area, and in the order of their intrusion are (1) rhyolite, (2) a basic series of diorite, gabbro, and peridotite, and (3) a series consisting of granite, quartz syenite, nepheline syenite, and related rocks. Of these the last-named series is the most abundant, the granite alone forming about 50 per cent of the surface rocks of the area. The various members of this group are found intrusive in the basal group of the area and also in the lower sedimentary formations. They are in turn overlain by later pre-Cambrian sediments. The period involved in the outflow of the various igneous formations of this group must have been a very long one and evidently constituted an important portion of the pre-Cambrian era, for the granite-syenite series itself represents a complex magma of variable though related rocks intruded at different dates. In the stratigraphy of this area, therefore, this group of igneous intrusives is one of the most important and occupies a well-defined position between the lower and upper pre-Cambrian sedimentaries.

The latest pre-Cambrian of the area consists mainly of conglomerate and quartzite overlying all the other formations above referred to. This group is represented by conglomerate and quartzite north of Wausau, conglomerate and quartzite at Arpin and North Mound, and conglomerate at Marathon and Mosinee.

In the north-central Wisconsin area the pre-Cambrian [a] was worn down to base-level by subaerial erosion before the much later Potsdam sandstone (upper Cambrian) was deposited upon it.

Nothing definite can be stated concerning the correlation of these various groups and formations with pre-Cambrian formations in other districts. It is believed, however, that the upper sedimentary series may be the stratigraphic equivalent of the Baraboo quartzite, which has been previously correlated [b] with the Ajibik quartzite of the Marquette and which belongs with the Middle Marquette (or Middle Huronian) series. This belief is based merely upon similarity to the Baraboo quartzite in the general character of the rock and upon similar relations to older igneous and sedimentary formations. The intrusive group of igneous rocks, consisting of rhyolite, diorite-gabbro, and granite-syenites, contains phases similar to those occurring in the igneous basement in the Baraboo district. The igneous intrusives are also similar to those bordering the southern side of the Menominee district. The lower sedimentary series of the area, consisting of much metamorphosed quartzites and slates in the form of fragmentary masses in the later intrusives, may be of Lower Huronian age, while the basal group of the area probably belongs with the Archean, since it shows the usual complex mixture and metamorphism of the igneous rocks below the Huronian sedimentaries.

Weidman,[129] in 1908, reports that in northwestern Wisconsin the pre-Cambrian is largely of igneous origin. The most prominent sedimentary areas are the prominent ridge of quartzite at the junction of Flambeau and Chippewa rivers and the numerous quartzite ridges along the divide of Chippewa and Red Cedar rivers, in Rusk, Sawyer, and Barron counties. In general these quartzites dip westerly away from the crystalline and schistose area, with strongly marked eastward escarpments overlooking the nearly flat plane of the older rocks. While no final conclusion has been reached concerning the relative age of these quartzites, the opinion is expressed that there are here represented at least two and probably three series. The quartzites, such as the small outcrops along the railroad about 3 miles east of Weyerhauser, are greatly metamorphosed and are correlated with the Rib Hill quartzite at Wausau. The prominent ridge of quartzite at the junction of the Flambeau and the Chippewa is correlated with the upper sedimentary series in north-central Wisconsin and the Baraboo quartzite. The prominent ridges of quartzite in eastern Barron County and in the adjacent parts of Rusk and Sawyer counties are but slightly metamorphosed, the bedding is in

[a] Weidman, Samuel, The pre-Potsdam peneplain of the pre-Cambrian of north-central Wisconsin: Jour. Geology, vol. 11, 1903, pp. 289–313.

[b] Weidman, Samuel, The Baraboo iron-bearing district: Bull. Wisconsin Geol. and Nat. Hist. Survey No. 13, 1904, p. 170.

general nearly flat lying, and the formation has a much younger aspect than the other two quartzite formations in the region.

For fuller summaries of articles referring to the Wisconsin ore-bearing districts see Monographs V, XIX, and XLVI of the United States Geological Survey.

SECTION 3. MINNESOTA.

SUMMARY OF LITERATURE.

Catlin,[130] in 1840, finds the red pipestone quarries of the Coteau des Prairies to consist of a perfectly stratified rock in layers of light-gray and rose- or flesh-colored quartz, the deposit being evidently sedimentary and of secondary age.

Norwood,[131] in 1847, describes various rocks on St. Louis River in the district between Fond du Lac and the Falls of St. Anthony, and from the mouth of Montreal River to the headwaters of Wisconsin River by way of Lake Flambeau. On St. Louis River a conglomerate is found to rest unconformably upon the lower slates, the junction of the slates and conglomerates being exposed.

Norwood,[132] in 1852, gives a great number of details as to the geology of middle and western Minnesota and the country adjacent to the southwest shore of Lake Superior, illustrating the relations of the shales, trap rocks, granites, etc., and showing the manner of intrusion of the eruptives and the complicated folding to which the strata have been subjected. At St. Louis and Black rivers the sandstone rests unconformably upon the underlying argillaceous and siliceous slates.

Eames,[133] in 1866, mentions different crystalline rocks as occurring at many points in northeastern Minnesota.

Eames,[134] in 1866, describes in Minnesota various granitic, igneous, and metamorphic rocks. The most prevalent rocks found in the northern part of the State are granite, porphyry, hornblende slates, siliceous slates, trap, greenstone, talcose slate, primitive schistose rock, gneiss, and Potsdam sandstone. The rocks of the upper Mississippi River are described. At Pokegama Falls the rock is a quartzite belonging to the Potsdam. There is also found along the river jasperoid rock with iron ore and argillaceous slate. In Stearns County are numerous exposures of granite. The varieties of rocks in the Vermilion Lake district are found to be very numerous.

Hall (James),[135] in 1869, finds in the vicinity of New Ulm, on Big Cottonwood River and on the Little Cottonwood, extensive exposures of quartzite. At New Ulm the rock is shown to be a metamorphosed quartz rock or conglomerate. This rock is succeeded below by compact quartz rock, with beds of syenite, which graduate still lower into purple or reddish quartz rock in distinct layers, alternating with shaly seams. The quartzite of this region has a thickness of not less than 1,500 feet. At Redwood Falls are found gneiss and granitic rocks of Laurentian age. The quartzites are regarded as of the age of the Huronian of Canada and equivalent to the quartzites of Wisconsin.

WHITE,[136] in 1870, describes the quartzites of Iowa, Minnesota, and Dakota. They are completely metamorphosed, intensely hard rocks, although the lines of stratification are distinct and there are frequently seen distinct ripple marks upon the bedded surfaces. Not infrequently the quartzite is conglomeratic. In them no fossils have been found. They are, however, regarded as belonging to the Azoic age because of their complete metamorphic character, because of their disturbed condition, and because the Lower Magnesian limestone at New Ulm rests upon the quartzites unconformably, and in this part of North America no disturbances are known to have occurred between the commencement and close of Paleozoic time.

WINCHELL (N. H.),[137] in 1873, states that the granitic and metamorphic rocks occupy a great portion of Minnesota. These are regarded as Laurentian and Huronian. Their lithological and mineralogical characters are complex and variable. The original nucleus was granite and syenite, and around these are arranged the metamorphosed slates and gneisses in upturned or even vertical beds, while intercalated with them are numerous injected beds or dikes of trap. The Sioux quartzite and those of New Ulm are placed as a part of the Potsdam sandstone. The Potsdam was laid down before the close of the volcanic disturbance, for the St. Croix beds of later age rest unconformably upon the Laurentian as well as upon the upturned beds of the Potsdam. In lithological character the Potsdam beds differ from those of the St. Croix, being hard and vitreous and usually of a red color. The Potsdam has a thickness of at least 400 feet.

WINCHELL (N. H.),[138] in 1874, gives details as to the geology of the Minnesota Valley. The quartzites in the vicinity of New Ulm and Redstone, referred to the Potsdam, are conglomeratic in places. In the valley there are rather numerous outcrops of granite, which are sometimes cut by trap dikes. At Granite Falls there are sudden changes from real granite to hornblende schist.

WIGHT, in 1877, discusses the relations of Lake Superior sandstone to Keweenawan traps along Kettle River. See summary in section 2, northern Wisconsin, page 183.

STRENG and KLOOS,[139] in 1877, describe in the upper Mississippi, a set of granitic, syenitic, dioritic, and gabbro-like rocks whch are referred to the Laurentian, while north of these is a zone of metamorphic schist—mica slate, talc slate, and clay slate—with gneiss-like rocks, which may be Huronian. South of Vermilion Lake is a region of granite, gneiss, and crystalline slate which belong to the Laurentian formation, while occupying a wide extent of country about St. Louis River are roofing slates and quartzites which are probably the representative of the Huronian. The igneous rocks at the west end of Lake Superior are without doubt of Potsdam age. On St. Croix River is a melaphyre which lies unconformably below a sandstone and conglomerate bearing fossils of Lower Silurian age, which relation points to the Huronian age of the melaphyre.

WINCHELL (N. H.),[140] in 1878, describes the crystalline rocks along the Northern Pacific Railroad. Syenites and granites occur at Little Falls on the Mississippi, and at Thompson on St. Louis River are slates, the former varying into a mica schist. In Pipestone and Rock counties are large exposures of quartzite which are lithologically like those of New Ulm, and like them are placed in the Potsdam.

WINCHELL (N. H.),[141] in 1879, gives the geological results of an examination of the northeastern part of Minnesota. The formations that compose the coast line of Lake Superior include, in descending order, (1) metamorphic shales, sandstones, and quartzites, cut by dikes and interbedded with igneous rocks, perhaps Sir William Logan's Quebec group; (2) sandstones, metamorphosed into basaltiform red rock, interstratified with igneous rock along the Palisades and at Black Point; (3) a quartzose conglomerate at the Great Palisades and at Portage Bay Island; (4) the quartzites and slates of Grand Portage Bay; (5) the jasper, flint, and iron-bearing belt of Gunflint Lake, Vermilion Lake, and Mesabi; (6) the slates and schists which the Canadian geologists designate Huronian; (7) Syenites, granites, and other rocks which have been classed as Laurentian; (8) the igneous rocks known as the Cupriferous series. The Cupriferous series seem to overlie several formations unconformably, and is interstratified with some of the later, especially with Nos. 1 and 2.

WINCHELL (N. H.),[142] in 1880, describes the Cupriferous series of Duluth. At Duluth the most important rock is the gabbro. This is intimately associated with a syenitic granite which is a metamorphic rock, all stages being seen, from the perfectly crystalline granite to the unchanged sedimentary layers. The Cupriferous series is regarded as Potsdam.

UPHAM,[143] in 1880, describes granites and gneisses at numerous localities in the Minnesota Valley. In the conglomerate opposite New Ulm and in the quartzite at Redstone are found numerous pebbles of quartz and jasper, but no granite pebbles are seen, although granite outcrops close to the west.

HALL (C. W.),[144] in 1880, describes the rocks between the mouths of Poplar and Devils Track rivers on Lake Superior to be dark-colored basic rocks of igneous origin belonging to the Cupriferous series, with the exception of a few beds of sandstone and conglomerate interbedded with the igneous rocks. The Sawteeth Mountains are formed as a result of combined igneous action and the folding of sedimentary strata and erosion.

WINCHELL (N. H.),[145] in 1881, gives many details as to the rocks of northeastern Minnesota. At Pigeon Point is a massive bedded or jointed formation like that at Duluth, with which it may be parallelized. The latter belongs to the Cupriferous series and the former to the Animikie, so that the Animikie appears to be a downward extension of the Cupriferous. At Mountain Lake the hills are short monoclines of gray quartzite, with beds of argillaceous and black slate, dipping to the southward usually at an angle of 8° or 10°, and covered with a greater or less thickness of trap rocks. In beds generally less than 50 feet, but sometimes 150 feet thick, the trap and slate dip together, so that the hills have gradual slopes toward the south, and steep or perpendicular slopes toward the north. The quartzite must be an immense formation, as it is seen at Grand Portage and all over Pigeon Point, and on the islands of the point. The quartzite formation of Gunflint Lake seems to graduate downward into the irony and carbonaceous Gunflint beds. A greenish, schistose, porphyritic rock, cut by veins of milk quartz, is found in a nearly vertical attitude on Gunflint Lake. This is supposed to be the Canadian Huronian, and underlies the quartzite and Gunflint beds apparently unconformably; at least, it is a distinct formation from the Grand Portage slates. The quartzite is locally a quartzite conglomerate. The Knife Lake serpentinous quartzite is regarded as Huronian. On the south side of Vermilion Lake are beds of jasper and iron which are regarded as the equivalent of the Gunflint beds. These are conformable with the magnesian schists and slates, which are in a vertical attitude. They pass down into the schists, and in places the schists and schistose structure penetrate the jasper and iron. It is suggested that the apparent conformity between the ferruginous beds and the underlying slates and schists is only a superinduced one, the original bedding, which may have been nearly horizontal, having been obliterated by the change.

WINCHELL (N. H.),[146] in 1881, describes the Cupriferous series of Minnesota as having a wide extent. In passing from the shore of Lake Superior it gradually becomes more changed and crystalline. The tilted red shales, conglomerates, and sandstones at Fond du Lac are the same as those associated with the igneous rocks all along the shore. At Fond du Lac they lie on white quartz pebbly conglomerate a few feet in thickness, which rests unconformably on the roofing slates of the Huronian, the same formation that succeeds to the red rock formation at Ogishki Manissi and Knife lakes, northwest of Grand Marais. The Cupriferous series differs from the Upper Laurentian or Norian only in the absence of beds of limestone, but, as the Lake Superior Cupriferous is Cambrian or Lower Silurian, it is inferred that the so-called Upper Laurentian, containing *Eozoon canadense*, is really Cambrian or Lower Silurian.

WINCHELL (N. H.),[147] in 1882, continues his description of localities. At Fond du Lac the detailed succession of sandstones and shales is given. The flint and jasper formations of Gunflint Lake appear to be in apparent unconformity with the underlying slates and syenites. On Ogishki Manissi Lake is found a great conglomerate. This conglomerate carries large rounded pieces of the Saganaga granite, which proves the greater age of that granite and the uncomformity to it of the conglomerate. The conglomerate also contains red jasper.

The descending succession in northeastern Minnesota is (1) the horizontal quartzites and slates running from Grand Portage to Gunflint Lake; (2) the conglomerate; (3) jaspery and calcareous Gunflint beds; (4) gray marble; (5) the tilted slaty Ogishki Manissi conglomerate; (6) amphibolitic and chloritic slates; (7) mica schists alternating with syenite; (8) syenites and granites of Saganaga and Gull lakes. Whether the Gunflint beds belong with the schistose and tilted slates and conglomerates of Ogishki Manissi Lake is an open question, although there are several things which indicate that they belong to the same series. The gabbro is found to have a widespread extent. It is suggested that if this gabbro and the associated red gneisses belong to the Cupriferous, the Minnesota and Wisconsin quartzites, as well as the red gneisses of the upper Mississippi Valley, may also belong to this series. The red syenite of Beaver Bay is a metamorphosed conglomerate which was brecciated and mingled with the trap. This red rock was fluidized so as to intrude itself in the form of belts and veins. A conglomerate at Taylors Falls, on the St. Croix, contains waterworn bowlders and traps of the region, but the superposition of the conglomerate on the trap can not actually be seen. This sandstone is fossiliferous. It is concluded that the Potsdam is represented by the copper-bearing series, while the underlying Animikie is equivalent to the Taconic of Emmons.

UPHAM,[148] in 1884, describes the crystalline rock outcrops in central Minnesota.

CHESTER,[149] in 1884, describes the rocks of the Mesabi and Vermilion iron ranges. The slates and schists on the south side of the Mesabi range are nearly horizontal. The rocks here found are precisely like those of the Penokee region of Wisconsin, and the two series bear the same relation to the Huronian series. The iron ore at Vermilion Lake is found in connection with jaspar and quartzite and is intimately bedded with the country rock, chiefly sericite schist, standing in a nearly perpendicular position. These rocks are the representative of the Michigan and Wisconsin iron deposits, and there is no doubt that they belong to the Huronian. The Vermilion deposits bear the same relations to the granite as do those of Mesabi, and they are regarded as the same formation.

Winchell (N. H.),[150] in 1884, gives the general succession of rocks in northeastern Minnesota, in descending order, as follows: (1) Potsdam, including the Keweenawan sandstones, shales, and conglomerates, changed by igneous gabbros and dolerites locally to red quartzites, felsites, quartz porphyries, and red granites. (2) Taconic group, including the Animikie series, the Gunflint beds, the Mesabi iron rocks, the Ogishki Manissi conglomerate (?), the Thompson slates and quartzites, and the Vermilion iron rocks. (3) Huronian group (?), including magnesian soft schists, becoming syenitic and porphyritic, found on the north side of Gunflint Lake, along the national boundary, and at Vermilion Lake. (4) Montalban (?), including mica schists and micaceous granites about Vermilion Lake and on Mississippi River. (5) Laurentian, including massive hornblende gneiss and probably the Watab and St. Cloud granites. This succession is parallelized with those of other writers given for the Northwestern States.

Winchell (N. H.) and Upham,[151] in 1884 and 1888, give detailed geological maps and descriptions of many of the counties of Minnesota, which include the Laurentian gneisses and granites of Mississippi and Minnesota rivers, the slates of the upper Mississippi, and the quartzites and conglomerates of Cottonwood, Pipestone, Rock, Brown, and Nicollet counties, which are regarded as Potsdam sandstone. The copper-bearing traps and conglomerates of Chisago and Pine counties are placed as Lower Cambrian. These reports contain nothing as to structural relations not found in the annual reports.

Winchell (N. H.),[152] in 1885, finds between Two Harbors and Vermilion Lake two rock ranges, the first being Mesabi proper and the second the Giants range. Resting unconformably upon the syenites of the Giants range are the Huronian conglomerates and greenstones of Vermilion Lake, while south of this range are the slates and quartzites of the Animikie, overlain by the gabbro and red granite of the Mesabi range, which is in turn overlain by the trap rocks of the Cupriferous series. The Huronian is represented as resting conformably below the Animikie, although not appearing at the surface. There are three iron-ore horizons—the titanic iron of the gabbro belt, the iron ore of the Mesabi range belonging in the Animikie, and the hematite of the Vermilion mines, which seems to be the equivalent of the Marquette and Menominee iron ores.

Winchell (N. H.),[153] in 1885, divides the crystalline rocks of the northwest into six groups, in descending order: (1) A granitic and gabbro group, which is a part of Irving's Cupriferous, and is by Hunt parallelized with the Montalban. It includes rocks which have passed for typical Laurentian, while the gabbros are eruptive and are like the

Upper Laurentian or Norian of Canada. The granites and gneisses show evidence of metamorphic origin. (2) A mica schist group, which is penetrated by biotite granite. (3) The black mica slate group, which often contains graphitic schists, in which are such ore deposits as the Commonwealth mine of Wisconsin. (4) A series of obscure hydromicaceous and greenish magnesian schists, along with quartzites and clay slates, with which are the more important bodies of hematitic iron ores, including those at Marquette and the magnetic belt at Penokee. (5) The great quartzite and marble group, which includes the marble of Menominee and the marble and lower quartzite of Marquette, the great conglomerate of Ogishki Manissi Lake, and the lower slate conglomerates of Canada. (6) The granites and syenites with hornblende schists. This is the lowest recognized horizon of the Laurentian. Nos. 3, 4, and 5 together are the equivalent of the Taconic system, 3 being the equivalent of the Animikie, while 5 is the equivalent of the Huronian of Canada. This succession is compared with the successions of Brooks and Irving in Michigan and Wisconsin.

WILLIS,[154] in 1886, describes the rock occurrences at several iron districts in northeastern Minnesota. At Pokegama Falls, on the Mississippi, are found outcrops of red quartzite and coarse-grained sandstone, sometimes metamorphosed to a quartzite and irregularly interstratified with hard specular ore. On Prairie River is found granite, southeast of which are quartzites, sandstone, and ore.

At Vermilion Lake the iron-bearing series has a dip of between 85° and 90°, the structure being regarded as an anticline, upon the north side of which is the Vermilion range and on the south side that of Two Rivers. The succession from the base upward is as follows: (1) Light-green, thinly laminated, chloritic schist. (2) Jasper of white, gray, brown, and bright red colors, interstratified with layers of hard blue specular ore, which also occurs in ore bodies of considerable extent running across the bedding; thickness 200 to 600 feet or more. (3) Chloritic schist, similar to 1; original thickness probably about 150 feet. (4) Quartzite, dark gray, white, or black, of saccharoidal texture, containing grains of magnetite which make it a readily recognized magnetitic formation; probable thickness 200 feet. (5) Conglomerate, consisting of sandstone pebbles and traces of black slate inclosed in siliceous chloritic schist. (6) Compact homogeneous rock, composed of quartz grains, chlorite, hornblende, plagioclase feldspar, and calcite. This rock may be an eruptive quartz diorite, but is considered a metamorphosed sedimentary transition bed between 5 and 7. (7) Black clay slate, fissile and sonorous. It occupies a broad area north of the Vermilion range. In section 28 huge masses of jasper form the crown of the arch and are embedded in green schist, with which they agree in strike and dip. The jasper blocks are rectangular and several hundred feet long; the ends of the bands come out squarely to the contact with the schist as to a fault.

Winchell (Alexander),[155] in 1887, gives detailed observations made on an extended trip in northeastern Minnesota. The region presents a series of schists flanked on the north and south by massive crystalline rocks. In the western part of the district these rocks are gneissic on both sides, but to the east the gneissic rocks on the south are replaced by gabbro and greenstone. The schists and bedded crystallines stand in a nearly vertical attitude, having a persistent and uniform strike and dip, the latter oscillating from 80° N. to 80° S. The rocks are sericitic, chloritic, micaceous, and hornblendic schists and argillites and graywackes. The schists grade into the gneissic rocks, there being nowhere an abrupt passage from one class to the other. In the passage from the schists to the gneisses there is first an increase in frequency of ramifying veins, then lumps of gneiss or granite in the schists, and next interstratification of the schists and gneisses. The conglomerate at Ogishki Manissi Lake, which attains an enormous development and contains varieties of granitic and quartzose bowlders, as well as flint, jasper, and other substances, is regarded as a local phase of the schists, as the bowlders are interbedded with the flinty argillites and sericite schists. The entire system of gneisses and schists is regarded as belonging to one structural system, as they all possess a common dip and pass by gradations into one another. The iron-bearing rocks are interlaminated with the country schists, and while they exhibit much persistence, they do not persist without interruption. In structure the region is a simple synclinal fold, the strata of which have a thickness of 106,204 feet. The succession from the bottom upward is granite, gneiss, micaceous and hornblende schists, graywacke, argillite schist bearing conglomerates, and sericitic and chloritic schists bearing iron ores. As the plainly fragmental rocks grade by imperceptible stages into the gneiss and granite, the whole is regarded as a sedimentary series. While granite pebbles are found in the conglomerates, this is not the underlying granite, as many of the fragments differ in character from the inferior granite.

Winchell (N. H.),[156] in 1887, gives very numerous details as to the geology of northeastern Minnesota. At several places there are transitions between the granite gneiss and a fine-grained mica schist. In the syenite are sometimes found angular fragments of mica schist. The Vermilion group is defined as including the lower portion of the complex series of schists designated Keewatin by Lawson. It embraces the mica schists and hornblende schists of Vermilion Lake and their equivalents, and lies between the graywackes on the one side and the basal syenites and granites on the other.

The iron ores of Minnesota are at three horizons. At the top are the titaniferous ores, which are associated with the gabbro and constitute what is locally known as the Mayhew iron range, and which are found from this range at many points all the way to Duluth. The nontitaniferous magnetitic ores occur at several localities associated with hematite ores and included in a quartz schist. These ores are comparable to those of the Penokee-Gogebic iron range on the south side of Lake Superior, and those of Black River Falls in Wisconsin. Adjacent to Vermilion Lake are hematite ores associated with jasper, which are inclosed in a schist, the bedding of which stands vertical. This schistose rock is probably of igneous origin; it overlies the jasperoid rocks unconformably, filling their cavities and holding fragments of them—all indicating its later origin. This igneous rock passes into a chlorite schist, and this into the sericite schists and graywackes, which show unmistakable evidence of an aqueous arrangement. The jasperoid hematite is a sedimentary rock, not an eruptive as has been supposed by Wadsworth. The rock was not, however, deposited in its present condition. The beds have been upturned, folded, crushed, and affected by intense chemical action. The ore is regarded as a result of chemical or metasomatic change. The general succession from above downward is as follows: (1) Gabbro. (2) Diabase dolerite. These rest unconformably upon the lower members. (3) Reddish gneiss and syenite, which includes the Misquah Hills, White Iron Lake, and the Giants range (Mesabi Heights). This is a case of a fusion of sedimentary beds in situ, although it is not generally complete. (4) Graywacke, sericite schist, argillite, quartzite, and jaspilite, which occur about Vermilion Lake. (5) Mica schist, hornblende schist, and diorite—the Vermilion group. (6) Mica schist and granite veined with syenite and granulite. (7) Lower syenites and gneisses, generally regarded as Laurentian. Nos. 3 to 7 are conformable, and Nos. 4 to 7 graduate into one another.

There is reason for believing that the Animikie rocks overlie the greenstone (2) and underlie the gabbro (1) of the above succession.

Winchell (N. H.),[157] in 1888, finds the Upper Huronian quartzites to be so similar to those of Pipestone, Cottonwood, and other counties in Minnesota that the former are regarded, with the latter, as Huronian. The Animikie on Gunflint Lake, while not found in exact superposition on the Keewatin, bears such relations as to render it probable that the two formations are discordant. A short distance north of the Animikie the Keewatin rocks are found with a dip of 80°, and these a little farther north grade conformably into the crystalline schists of the Vermilion group, and these still farther north by transition pass into the gneisses and syenites of the Laurentian. The Animikie rocks are found resting uncomformably on the gneiss west of Gunflint Lake. The gabbro is observed overlying the Animikie at many places, the Pewabic quartzite, the Keewatin rocks north of Gunflint Lake, and the syenite gneiss north of Flying Cloud Lake.

In passing from Gunflint Lake the Animikie is found to have a dip as high as 30°. Near Gobbemichigomog Lake there is a gradation from the flat-lying Animikie to rocks in a broken and tilted condition, and from these into the Ogishki Manissi conglomerate, with which they are interstratified. There is also extending from Stuntz Island in Vermilion Lake past Ely to near Ogishki Manissi Lake an older schistose eruptive-looking conglomerate associated with the Keewatin schists, and therefore older than the Ogishki conglomerate. The beds on the north side of Gunflint Lake resemble those on the south side of the Giants range and belong in the same stratigraphic position near the base of the Animikie. The gneiss is regarded as a metamorphosed sediment, because of the gradation of the Keewatin beds into it, and because it cuts through and is interstratified with the Keewatin. The Keewatin schists are interstratified eruptives and sedimentaries, as is the Cupriferous series. On Kekekabik Lake there is an extension of the Ogishki Manissi conglomerate westward. The green schist conglomerates here found are apparently of about the same date as the Ogishki conglomerate or else its immediate conformable successor. The Animikie slates associated with this green schist conglomerate are also in conformable succession to the green schists, but it is likely that this conformity would not be found in the vicinity of the old volcanic vents.

WINCHELL (ALEXANDER),[158] in 1888, finds upon Wonder Island, in Saganaga Lake, a conglomerate which contains abundant rounded pebbles in a groundmass of syenite. The lower limit of the conglomerate is rather abrupt, and whether it overlies the syenite or grades into it is uncertain, but it is figured as overlying the syenite. The syenite is regarded as erupted after the conglomerate existed and the conglomerate was not laid down on the solidified syenite. The Animikie slates are found resting unconformably upon vertical schists, gneisses, and syenites at several points on Gunflint Lake, 2 miles west of Gunflint Lake, and on the north side of Epsilon Lake. On the west side of Sea Gull Lake the conglomerate and syenite are interbedded. This conglomerate is thought to be comparable with that of Wonder Island. On the north side of the same lake the syenite contains sharply limited rounded pebbles and irregular masses of hornblendic and diabasic material. On Epsilon Lake the argillite has schistic planes standing vertical, while the bedded structure has a dip of only 23°.

Summing up the succession: At the base are the granitoid and gneissoid rocks in three areas, the Basswood, White Iron, and Saganaga lakes. These granitic masses everywhere have a bedded structure more or less distinct. They are traversed by quartzose and granulitic veins, as well as dikes of diabase. The gneisses and granites are flanked by vertical crystalline schists of the Vermilion group. The transition from the gneisses to the crystalline schists is never abrupt, but is a structural gradation, near the line of junction the beds of gneisses and schists occurring in many alternations. Above the Vermilion group are the Keewatin semicrystalline schists, the two series being everywhere conformable; but there is a somewhat abrupt change from one group to the other, and there is a possibility that the original unconformity has been destroyed by lateral pressure, although such an unconformity is thought improbable. There has been no actual connection traced between the Keewatin schists north of Gunflint Lake and those of Knife Lake. The Keewatin schists are almost everywhere vertically bedded. When the bedding is obscure this is sometimes due to the action of erupted masses, but more often the metamorphosed condition of the strata is not ascribable to any visible cause. The Keewatin schists include graywacke, argillite, sericite schist, chlorite schist, porphyrellyte schist, and hematite.

The Ogishki conglomerate is placed as a part of the Keewatin system, as it is traced by actual gradations into the adjoining argillites. These argillites and associated schists are in continuity with the argillites and schists of Vermilion Lake, while in the conglomerate itself are local developments of sericite schist. The bedding of the conglomerate is nearly vertical; its pebbles are metamorphosed; they include numerous varieties, among which are syenite resembling the Saganaga syenite, greenstone, porphyry, red jasper, flint, quartz, petrosilex, ordinary syenite, diorite, porphyroid, siliceous schist, and carbonaceous siliceous argillite. On structural as well as lithological grounds the Ogishki conglomerate seems to be a part of the Keewatin, although there are some reasons for suspecting it to grade into the Animikie. That the Keewatin schists are eruptive is regarded as improbable.

The Animikie series, resting unconformably upon the Keewatin, stretches from Thunder Bay past Duluth to Mississippi River, and perhaps includes the slates as far west and north as Knife Lake. The Animikie formation is generally in a nearly horizontal position, the dip not being more than from 5° to 15°. The formation is essentially an argillite, which embraces jaspery, magnetitic, hematitic, and sideritic beds. At Gobbemichigomog Lake the Animikie, represented by the "muscovado," is in its characteristic horizontal position, while the vertically bedded terrane underlies it.

For the system of semicrystalline schists subjacent to the Animikie, to which the term Keewatin has been applied, Marquettian is proposed. The succession of terranes in northeastern Minnesota is, then, in descending order, as follows: (1) Huronian system, more than 4,082 feet thick, including the magnetitic group, siliceous group, and argillite group; (2) Marquettian system, 27,500 feet thick, including the Ogishki group, 10,000 feet thick, the Tower group (earthy schists), 15,000 feet thick, and the graywacke group, 2,500 feet thick; (3) Laurentian system, 89,500 feet thick, including the Vermilion group, more than 1,500 feet thick, and the gneissic group, more than 88,000 feet thick. Total, more than 121,082 feet.

WINCHELL (H. V.),[159] in 1888, gives detailed observations about many localities in northeastern Minnesota. The mica schist and interbedded gneiss are cut by granite veins at numerous places.

HALL (C. W.),[160] in 1889, describes the distribution of the granites of the Northwestern States, and particularly those of Minnesota. They are found to be either intrusive or granitic veinstones, the latter being insignificant in quantity. The granites of Minnesota as to age are probably later than the Laurentian floor of the continent, but earlier than the close of the Agnotozoic era. There are three or four grand periods of eruptive activity.

WINCHELL (N. H.),[161] in 1889, gives a summary of the results of work on the crystalline rocks of northeastern Minnesota. In many points the conclusions and facts are the same as in the previous reports. The Laurentian age is made to include the gneiss, granite, and syenite, but excludes the crystalline schists. It is the fundamental gneiss of Minnesota. Associated with this fundamental gneiss are areas of massive eruptive syenite which are regarded as due to the hydrothermal fusion of the gneissic belts. The gneisses grade into the Vermilion schists, which are the equivalent of Lawson's Coutchiching. Along their contact the Laurentian plays the part of intrusive rocks, which is indicative that the opening of Vermilion age was one of violent volcanic action. The beds have subsequently been affected by hydrothermal fusion, which has tended to unify the Laurentian and Vermilion systems.

The Vermilion group passes by conformable transition into the Keewatin. The character of the Keewatin rocks indicates that there was active volcanic action during the whole period and that the ejectamenta were received and distributed by the waters of the surrounding sea. This is indicated by the alternation of breccias and volcanic material with truly sedimentary strata. The Keewatin is the iron-bearing formation. The iron ore is associated with the jaspilite, which is of sedimentary origin. Parallel with the Keewatin of Minnesota is the serpentine and dioritic group of Rominger in the Marquette region. Above this group in both regions is a profound unconformity.

The Animikie series of Minnesota, bearing iron at one horizon, is the equivalent of the Marquette series bearing the iron group of Rominger, of the Penokee-Gogebic series of Michigan and Wisconsin, of the Mesabi range in Minnesota, of the Black River iron-bearing schists in Wisconsin, and of the quartzites of the Black Hills. All are of Taconic age, for the Lower Cambrian is equal to the Taconic, the Huronian is equal to the Taconic; therefore the Lower Cambrian is equal to the Huronian.

In the Potsdam sandstone, which is unconformably on the Taconic, is included the upper quartzites of the Original Huronian, certain of the quartzites of Marquette, the Sioux quartzites of Dakota, and the quartzites of Minnesota and Wisconsin. This is also the age of the Copper-bearing rocks, which are an alternation of basic and acidic eruptions with interbedded sandstones and conglomerates. The great gabbro eruption is later than the beginning of the Potsdam age. Unconformably above the Potsdam is the St. Croix sandstone.

The general succession in descending order is, then, as follows:

Calciferous	Magnesian limestones and sandstones	*Dikelocephalus* horizon.
St. Croix	Sandstones and shales	
Overlap unconformity.		
Potsdam	Quarzite, gabbro, red granite, and Keweenawan	*Paradoxides* horizon.
Overlap unconformity.		
Taconic	Black and gray slates and quartzites, iron ore (Huronian, Animikie)	*Olenellus* horizon.
Overlap unconformity.		
Keewatin	(Including the Kawishiwin or greenstone belt, with its jaspilite) sericitic schists and graywackes	Archean.
Vermilion	(Coutchiching) crystalline schists	
Eruptive unconformity.		
Laurentian	Gneiss	

WINCHELL (H. V.),[162] in 1889, gives further observations on the iron regions of Minnesota. On the Giants range the Animikie is found to rest upon the syenite. Here is a semicrystalline rock between the two, which grades into the syenite. The character of the transition is not metamorphic, but rather fragmental, there appearing to be a certain amount of loose crystalline material which has resulted from the decay and erosion of the syenite lying on top of this rock in the bed of the sea upon and around which the Animikie sediments were deposited. The coarse detritus grades up into the fine detritus of the Animikie. The Animikie beds are found also to rest unconformably upon the upturned edges of the Keewatin schists. The same relations are found to prevail in the Birch Lake region. The gabbro containing ores in the vicinity of Kawishiwi River is found to contain fragments of the Animikie slates and quartzites, and is, therefore, of later origin. At Gunflint Lake the Animikie rests unconformably upon the Keewatin, and is found upon greenstone. The Keewatin schists are largely of eruptive origin. The contacts of the jaspilite with the basic schists are abrupt and angular, and numerous fragments are found contained in the schists. The jaspilite is regarded as a sedimentary formation which was broken up and involved in the eruptions of Keewatin age. The Huronian quartzite associated with the magnetite, lying unconformably upon the syenite, is believed to lie conformably upon the Animikie slates.

GRANT,[163] in 1889, gives geological observations made in northeastern Minnesota. North of Gunflint Lake the vertical Keewatin and crystalline schists, with an east-west strike, strike directly across a range of immediately adjacent gneisses, the schists showing no evidence of being twisted or bent within 200 feet of the gneiss. In the syenites of Gunflint Lake are found fragments of schist, which indicates that the syenite is eruptive later than the schists. At Winchell Lake the syenite upon the top grades down by an apparent transition into gabbro. The gabbro is sometimes cut by veins or dikes of syenite, which indicates that the latter is of later age, although the syenite is generally below the gabbro.

WINCHELL (ALEXANDER),[164] in 1889, maintains that the Saganaga and West Sea Gull granite conglomerate before described is produced from a fragmental rock by selective metamorphism, the completely crystalline gneissoid rocks retaining rounded fragments which are residual clastic material. The conglomerate of Wonder Island is not one consisting originally of a mass of pebbles over which a fluid magma has been poured, for the pebbles are not in contact; they could not have lain where they are before the gneissic magma existed. The gneissic magma was present, and it was this which supported the pebbles and prevented their contact. It is, then, contemporaneous with the pebbles. The magma must have been plastic, but it was low temperature igneo-aqueous plasticity.

WINCHELL (N. H.),[165] in 1889, in a general discussion of the origin of the eruptive rocks, maintains that there are four epochs of basic eruption in Minnesota, the first represented by the Vermilion group; the second, by the rocks succeeding the graywackes; the third, by those succeeding the Animikie, and the fourth, by those of the Cupriferous formation.

MEADS,[166] in 1889, describes the Stillwater, Minn., deep well. The well, after passing through about 700 feet of St. Croix and Potsdam sandstone, enters rocks which are in every respect identical with those of Keweenaw Point; hence the Keweenaw rocks are below the light-colored sandstones of the Northwest. For the first 1,500 feet these are brown shales and brown feldspathic sandstones; these gradually assume the characters of a volcanic detrital tuff—amygdaloid; and finally, at a depth of 3,300 feet, unmistakable beds of trap were encountered alternating with sandstone beds. At this depth grains of native copper were seen in the drillings.

WINCHELL (N. H. and H. V.),[167] in 1889, maintain that the iron ores of the Keewatin of Minnesota are not derived from a carbonate, but are probably a direct chemical precipitate; for there is no evidence of the existence of carbonate of iron at any time, and the nature of the country rock is such as to imply that no carbonates in amounts required could have been deposited at the time the rocks were formed.

WINCHELL (ALEXANDER),[168] in 1890, repeats his general conclusions as to the stratigraphy in northeastern Minnesota and gives a succession as follows, in descending order:

V. Uncrystalline schists (Animikie, Huronian).
IV. Semicrystalline schists (Keewatin).
III. Crystalline schists (Vermilion).
II. Gneissoid rocks.
I. Granitoid rocks (Laurentian).

WINCHELL (N. H. and H. V.), [169] in 1890, state that the iron ores of Minnesota are at five geological horizons, as follows, in descending order:

(1) The hematites and limonites of the Mesabi range, the equivalents of the hematites of the Penokee-Gogebic range in Wisconsin.

(2) The gabbro titaniferous magnetites near the bottom of the rocks of the Mesabi range.

(3) Olivinitic magnetites, just below the gabbro in the basal portion of the Mesabi rocks.

(4) The hematites and magnetites of the Vermilion range in the Keewatin formation.

(5) The magnetites of the crystalline schists of the Vermilion formation.

It is maintained that the upper iron deposits of the Mesabi and those of the Penokee-Gogebic are the equivalents of the Taconic ores of western New England.

WINCHELL (N. H.),[170] in 1891, gives numerous additional field observations. The relations of the jaspilite, argillite, and green schist are considered, and the argillite at least is regarded as a sedimentary rock. The position of the Pewabic quartzite is left uncertain. It is considered, however, to overlie the Animikie black slate, unless there are two great quartzites. This quartzite has heretofore been made the parallel of the great quartzite that overlies the Animikie unconformably, but it is possible that it runs below it conformably. In the Stuntz conglomerate is found a large bowlder which contains pebbles of chalcedonic quartz and quartzose felsite and the porphyrel at Kekekabik Lake. A study of the ore formation leads to the conclusion that all three of the known agencies of rock formation were intermittently at work and concerned in forming the iron ore, viz: Eruption, to afford the basic eruptive material; sedimentation, to arrange it (in the main), and chemical precipitation in the same water, to give the pure hematite and the chalcedonic silica. The great gabbro of the Cupriferous formation is regarded as lying below the Animikie, among other reasons because it lies next to and immediately south of the gneiss of the Giants range without the appearance of any black slate between them, and because bowlders of characteristic gabbro, red syenite, and quartz porphyry occur abundantly in the later traps of the Cupriferous.

WINCHELL (N. H. and H. V.),[171] in 1891, give an extended treatment of the iron ores of northeastern Minnesota and the rocks in which they are contained. Excluding the Cretaceous, the rocks here found are divided as follows, in descending order: Keweenawan—trap rocks, tuffs, red sandstones, and conglomerates (Potsdam?); Animikie—black slates, gray feldspathic sandstones, and limestones; Norian—gabbro of the Mesabi Hills, red granite, quartz porphyry, and red felsite; Pewabic quartzite (granular quartz, Potsdam?); Keewatin—sericitic schists, graywackes, greenstones, agglomerates, and jaspilite; Vermilion—mica schists and hornblende schists (Coutchiching?); Laurentian—sedimentary, gneissic and eruptive, massive or porphyritic. The Keweenawan to the Pewabic inclusive are placed in the Taconic, and the Keewatin to the Laurentian inclusive in the Archean or Azoic.

The jaspilite and schist of the Keewatin are in some places minutely interlaminated; at other places the jasper is in irregular layers, none of which have any great extent and all of which finally pinch out; at still other places it is in oval forms, the greater lengths being parallel with the schistose structure. Again, the jaspilite is in great fragments within the green or massive diabasic schists, the masses having in places such relations with one another as to show that they are a broken continuous layer. The branches from the large bodies of jaspilite are supposed to be caused by the crumpling, breaking, and squeezing of the entire rock structure, by which the thinner sheets have been buckled out and thrust laterally among the inclosing schists. The ore always occurs associated with the jaspilite, the forms of the deposits being exceedingly irregular. The ore and jasper are regarded as a direct chemical deep-sea precipitate, accompanied and interrupted by repeated ejections of basic volcanic rocks, from which the iron for the ore is extracted.

The rocks of the Animikie equivalent to the Huronian and included in the Taconic consist chiefly of carbonaceous and argillaceous slates with siliceous slates, fine-grained quartzites, and gray limestones. At the bottom of the series is a fragmental quartz sandstone 300 feet in thickness, which is named the Pewabic quartzite. The slates, conglomerates, and quartzites are profoundly affected and intermingled with eruptive material similar to that found so abundantly in the Keewatin. These beds have the appearance of consolidated beds of basic lava or of porous tuff, but where this prevails there is a sensible gradation from the dark, trap-looking beds to thin beds of slate. At

Ogishki Lake there is a slate conglomerate similar to that on the north shore of Lake Huron. This conglomerate is not the same as the agglomerates of the Keewatin, such as those on Stuntz Island, at Vermilion Lake, and at Ely. The Keewatin is always nearly vertical, while the dip of the Taconic rarely exceeds 15°. The iron-ore beds of the Taconic are the quartzose, hornblendic, magnetitic group of the Pewabic quartzite; an impure jaspilite, hematite, and limonite group; a carbonated iron group; and a gabbro titanic iron group. The jaspilitic hematite group has the same lithological peculiarities as the jaspilite beds of the Vermilion range. The gabbro in which the titanic iron occurs constitutes the Mesabi range. This has been before regarded as the base of the Keweenawan, into which it fades upwardly, but it has been found that this great gabbro flow was outpoured at an earlier date, and it is placed at or near the bottom of the Animikie.

Winchell (H. V.),[172] in 1891, states that the syenite of Saganaga Lake is conglomeratic in places and contains pebbles which are similar to one another, being mostly composed of lamellar augite, with or without grains of feldspar, but there are no pebbles of syenite or jasper, such as occur in the Keewatin conglomerates. In the Saganaga granite, at the end of the portage on Granite River, is a band of silica 1½ inches in diameter and 3 feet in length. North of Saganaga Lake the syenite grades into chloritic syenite gneiss, and this into thick-bedded to massive Keewatin rocks. From these facts it is concluded that the syenite is simply a result of locally intense metamorphism.

Bayley,[173] in 1892, concludes, after a microscopic examination of the specimens obtained in the neighborhood of Akeley Lake, from the formation designated Pewabic quartzite by the Minnesota geologists, that they are granulitic and quartzose phases of the gabbro, and that none of them are sedimentary rocks. These granulitic and quartzose gabbros are traced into ordinary gabbros; consequently the Pewabic quartzite is a part of the gabbro. The ore beds of the Akeley Lake series, interstratified with these granulitic gabbros, also belong with the overlying gabbro and not with the Animikie. This conclusion agrees with that reached by Chauvenet in 1883 and 1884. This iron-bearing silicified gabbro has been traced by Bayley southwestward through secs. 25, 35, 34, T. 65 N., R. 5 W., to Michigamme Lake. The same silicified gabbro belt has been found by Merriam at Lake Gobbemichigomog.

Grant,[174] in 1892, states that the Animikie rests unconformably upon the Saganaga granite, that the Ogishki conglomerate is intruded by the Saganaga granite, and therefore that the Ogishki conglomerate is earlier than and separated by a great structural break from the Saganaga granite. As the Keewatin has the same relations to the Saganaga granite as the Ogishki conglomerate, the same thing is true of the Animikie and Keewatin. The Ogishki conglomerate is younger than the most of the Keewatin, but is considered as a part of it.

HALL and SARDESON,[175] in 1892, describe the upper Cambrian rocks of southeastern Minnesota as resting unconformably upon a pre-Paleozoic floor. The base of the Potsdam is usually conglomeratic. At Minneopa a well 800 feet deep passed through a conglomerate for a distance of 225 feet, the pebbles of which are vitreous quartzite like those occurring in Cortland, Watonwan, and Cottonwood counties. A conglomerate containing granite débris is found on Snake River about 2 miles above Mora, and 3 miles distant from the Ann River knobs of hornblende-biotite granite, the clastic appearing to be derived from the granite. At Taylors Falls a conglomerate made up of pebbles of diabase rests upon the diabase of St. Croix River. These underlying formations are Archean and Algonkian rocks.

BAYLEY,[176] in 1893, 1894, and 1895, gives a detailed petrographic study of the basic massive rocks of the Lake Superior region, and especially of the great gabbro of northeastern Minnesota. The normal phase of the gabbro is found to have a typical granitic structure and to differ essentially from all of the basic intrusive rocks of the Animikie series and from all other Keweenawan basic rocks, none of which have a distinctly granitic structure. Upon the border of the main mass of gabbro are peculiar rocks which are interlaminated with quartzose bands. These are shown to be but peripheral phases of the gabbro. It is concluded that further field work will probably show that the gabbro is either a batholith, well toward the base of the Keweenawan series, or that it is an eroded mass, upon top of which the later Keweenawan beds have been deposited.

WINCHELL (N. H.),[177] in 1893, gives the following as the general consensus of opinion of several geologists as to the descending succession of the rocks of northeastern Minnesota.

1. Keweenawan or Nipigon series unconformably beneath rocks bearing the *Dikelocephalus* fauna, and consisting of fragmental and eruptive beds, the upper portions being almost entirely red sandstones.

2. Alternating beds of eruptive sheets and fragmental rocks. The fragmentals are thin-bedded slates, actinolite schists, magnetitic jaspers, cherts, and quartzites. The sheets are ordinary eruptives or pyroclastics.

3. Immense quantities of true gabbro, much of it bearing titaniferous magnetite, are associated with contemporaneous felsites, quartz porphyries, and red granites. This gabbro includes several masses of the next older strata, particularly the Pewabic quartzite.

4. The Animikie. This series is characterized by a great quartzite associated with the iron ores and cherts. The quartzite (Pewabic) lies unconformably on all the older rocks. In many places it is conglomeratic, bearing débris of the underlying formations. Within it are mingled volcanic tuffs from contemporaneous eruptions. The Pewabic quartzite includes that of Pokegama Falls, on the Mississippi River, and of Pipestone County. In the vicinity of contemporaneous volcanic disturbances its grain is fine, like jaspilite, and sometimes it has acquired a dense crystalline structure from contact with the gabbro.

5. The Keewatin. This is a volcanic series of great thickness, being composed mainly of volcanic tuffs, presenting more or less evidence of aqueous sedimentation, but conglomerates, graywackes, quartzitic schists, and glossy serpentinous schists are present. The Kawishiwin formation, apparently the upper member of the series, embraces the great bulk of the greenstones, chloritic schists, jaspers, and hematites. The iron ores are in lenticular lodes, and stand upright, conformable with the general position of the rocks.

6. The Keewatin series becomes more crystalline toward the bottom, and passes conformably into completely crystalline mica schists and hornblende schists, which are named the Vermilion series. The rocks are usually stratiform, contain magnetic iron ore, and embrace some dark massive greenstone belts, in which no stratification bands are visible.

7. The Laurentian. When not disturbed by upheaval the Vermilion schists pass into Laurentian gneiss, there being a gradual increase in the feldspathic and siliceous ingredients. Even after the Laurentian characters are apparently fully established conformable bands of Vermilion schists reappear; from which it is plain that the base of the Vermilion is an uncertain plane, which can not be located exactly. This normal passage from the Vermilion to the Laurentian is frequently disturbed by the intrusion of numerous dikes of light-colored granitic and basic rocks. These were both in a fluid state, the only nonfluid rocks being the schists which are embraced within them in isolated pieces. In a similar manner small areas of Laurentian granite, sometimes directly in contact with the schists, have the imperfectly crystalline condition of the Keewatin.

Nos. 3 and 4 are separable from No. 2 by divergence in dip and strike, as well as by a marked difference of lithology. There is consequently some evidence of unconformity between them. Below No. 4 is a great physical break, which separates Nos. 1, 2, 3, and 4 from 5, 6, and 7 throughout the Lake Superior region. This break is the greatest erosion interval which has been discovered in Paleozoic geology. Nos. 1, 2, 3, and 4 together constitute the Taconic; Nos. 5, 6, and 7 constitute the fundamental complex or Archean, which is a unit in its grander features.

The structure and origin of the foregoing series are considered in some detail. It is concluded that stratification can always be discriminated from schistosity or slaty cleavage by the varying shades of color bands which sweep across the surface of the rocks and by gradations of the kind and size of grains across the bands. These layers may vary from one-sixteenth of an inch to several inches or several feet across.

LAWSON,[178] in 1893, gives a petrographical and structural account of the anorthosites of the northwest shore of Lake Superior. The anorthosite is wholly massive, completely granitic in structure, and is composed almost entirely of basic feldspar, varying in composition from labradorite to anorthite. The rock occurs near Encampment Island, in the vicinity of Split Rock Point, at Beaver Bay and vicinity, at Baptism River, on the slopes of Sawteeth Mountain, and at Carlton Peak. In nearly all of these localities the rock is found in rounded, dome-shaped masses below the other eruptives of the coast. It is cut by these different eruptives, and in the lava flows are found very numerous blocks and bowlders of anorthosite, which were caught at the time of their extrusion. These facts show that the anorthosite is of pre-Keweenian age, and as the anorthosite is a plutonic rock it must have suffered profound erosion prior to the extravasation of the Keweenian eruptives. Norwood, Irving, and Winchell have described the blocks of anorthosite in the lavas at some of the points. Winchell regarded the anorthosite at Split Rock as older than the eruptives, containing masses of them, and Irving reached the same conclusion in reference to the anorthosite at Carlton Peak. However, none of them differentiated the anorthosite mass from the general aggregation of volcanic flows constituting the Keweenian series of the Minnesota coast. The surface of the pre-Keweenian anorthosite is domed and hummocky like that of the other Archean terranes of Canada, and it is thought to have been only modified by Pleistocene erosion. The interval between the anorthosite and the Keweenian is probably the same as the pre-Paleozoic interval which effected the reduction of the Archean to the great hummocky plain to which it was reduced before the Animikie was deposited upon it. As the Keweenian rests directly upon the anorthosite, the Animikie is absent for the middle third of the Minnesota coast. Irving places the thickness of the Keweenian of the area at 20,000 feet, stating that it may reach 22,000 or 24,000 feet. The maximum thickness of the Keweenian is not more than one-tenth of this thickness. Irving's subdivision of the Keweenian into groups and his estimates of the thickness of various portions of the series are of little value—a statement which it is as painful to make as it is necessary in the interests of sound geology. The anorthosite is provisionally correlated with the Norian of the Province of Quebec, but as this correlation is merely a hypothesis the name Carltonian is suggested for this formation.

GRANT,[179] in 1893, describes and maps the geology of Kekequabic Lake in northeastern Minnesota. By far the larger proportion of the rocks represented are clastics, which are divided for convenience into four groups. The first and most extensive group is the slate formation, consisting largely of argillites with smaller amounts of fine and coarse graywackes and grits, the coarser phases becoming distinctly conglomeratic in places. The second group consists of coarse conglomeratic rocks, which are a part of the Ogishke conglomerate. The third group is made up of certain fissile green schists, which are believed to be water deposited, and probably originally formed from fine volcanic ash. The fourth group consists of volcanic fragmental material, in part deposited in water. All of these clastic rocks now stand in nearly vertical positions, with a strike a little north of east.

Sharply marked off from the clastic rocks are four types of igneous rocks—hornblende porphyrite, granite, diabase, and gabbro. The granite is divisible into two types, ordinary granite and granite porphyry, in both of which the ferromagnesian constituent is almost exclusively pyroxene and the predominating feldspar anorthoclase. The origin of the granite is truly eruptive, having broken through the surrounding clastics; the rock is not formed, as held by N. H. and A. Winchell, from the recrystallization in situ of the sedimentaries of the region.

The slate formation, the green schist, and the volcanic tuff belong to the Keewatin, the Minnesota equivalent of the Lower Huronian. The conglomerate contains pebbles, many of which are similar to some of the Keewatin rocks, and it seems to belong to a newer series, although as yet no unconformity between the conglomerate and other rocks has been discovered. Following Lawson, it is believed that the conglomerate is a part of the Keewatin, probably separated from the lower part of that series by an unconformity, and that it is much older than the Animikie. However, the question whether the clastics belong to one or two series is as yet open.

The porphyrite and the granite are of Keewatin age. The porphyrite is regarded as contemporaneous with the deposition of volcanic tuff and green schist, and the granite is believed to date from the folding of the Keewatin. The age of the diabase dikes is not known; they are perhaps contemporaneous with the great diabase intrusions in the Animikie. The gabbro is of early Keweenawan age.

Bayley,[180] in 1893, gives fully the field occurrences, relations, and petrography of the eruptive and sedimentary rocks of Pigeon Point. The oldest rocks are interbedded Animikie slates and quartzites. Cutting the Animikie rocks is an olivine gabbro, which occupies all the higher portions of the point. It is in all probability the lower portion of a large dike whose upper part has been removed by denudation. Between the gabbro and the bedded rocks in many places are successively a coarse-grained red rock, a fine-grained red rock (quartz keratophyre), and a series of contact rocks. The main masses of the keratophyre occupy a position between the Animikie sedimentaries and the gabbro. This rock has all the characteristics of an eruptive younger than the gabbro. The coarse-grained rocks between the gabbro and the keratophyre are intermediate in character between the two, and grade into them. They are therefore regarded as a contact product formed by the intermingling of the gabbro and keratophyre magmas. The keratophyre also apparently grades into the Animikie slates and quartzites, there being three zones showing different grades of alteration of the sedimentary rocks due to the contact with the igneous rock.

From the peculiar relations it is regarded as probable that the keratophyre is of contact origin; that is, it was produced by the fusion of the slates and quartzites of the Animikie through the action upon them of the gabbro. The magma thus formed then acted in all respects like any intrusive magma. It penetrated the surrounding rocks in the form of dikes, and solidified as a soda granite under certain circumstances, and under others as a quartz keratophyre. Cutting all of the previously mentioned rocks are diabase dikes.

Grant,[181] in 1893, publishes his note book made on a trip in northeastern Minnesota. The areas visited were those of Kawishiwi River, Snowbank Lake, Kekequabic Lake, and Saganaga Lake. In the study of these areas there was no evidence found of a transition from semicrystalline and crystalline schists into granite. On the other hand, abundant evidence was found of the eruptive nature of the granite rocks into the surrounding sediments. The gneissic and so-called bedded structure in the granitic rocks is not as common as has been supposed, the structure usually being truly granitic. The Kawishiwi River and Snowbank Lake massive rocks are hornblende syenites. The Saganaga rock is a coarse hornblende granite. That around Kekequabic Lake is a pyroxene granite, and associated with it is peculiar pyroxene granite porphyry. The intrusive character of the granite is particularly well shown between secs. 31 and 32, T. 63 N., R. 10 W., near Clearwater Lake, and in the SE. ¼ SW. ¼ sec. 26, T. 64 N., R. 9 W., on the west shore of Snowbank Lake. Along Kawishiwi River the rocks mapped comprise gabbro, syenite, mica schist, graywacke, etc., greenstone, and quartz porphyry. The gabbro is the most recent, and covers part of the older rocks. The syenite is older than the gabbro, and is younger than the greenstone and mica schist, both of which it cuts. The mica schists, graywackes, etc., are vertical, and have a general east-northeast strike. These have been formerly mapped as belonging to the Vermilion series, but there seems to be good reason for putting all of this type of rock in the area mapped into the Keewatin. The greenstone is presumably of Keewatin age, and is probably younger than the mica schists, graywackes, etc. Quartz porphyry dikes are found cutting the greenstones in several places, but they have not been seen in the other rocks in the immediate vicinity.

LAWSON,[182] in 1893, gives a résumé of the geology of northeastern Minnesota adjacent to Lake Superior. Surrounding the lake are four geological provinces, viz (from the top downward), the Potsdam, Keweenian, Animikie, and Archean.

The rocks of the Potsdam are flat-lying shaly sandstones, generally of a red color.

The Keweenian occupies the entire Minnesota coast from Duluth to Grand Portage. The series consists in this area of a well-stratified series of volcanic flows, having a gentle lakeward dip, which does not generally exceed 10°. The sedimentary formations are represented in the series, but occupy less than one-half per cent of the coast line. The lavas are largely vesicular or amygdaloidal in character, and in those of acidic composition, in which the vesicular structure is not so well developed, are numerous irregular joints. The series has been invaded by many later intrusive masses, which occur as nearly vertical dikes, or more commonly as injected sills which coincide with the planes of stratification of the bedded flows. Since the time of the outflow of the Keweenian rocks the strata have suffered comparatively little disturbance, the prevalent lakeward dip being probably due to the attitude of the slopes upon which the lavas flowed, rather than entirely to a differential movement of once horizontal strata. The pre-Keweenian labradorite rocks exposed at a number of points were profoundly eroded before the Keweenian was deposited upon them, and they were presumably Archean.

The Animikie rocks occupy the shore of the lake from Grand Portage to Port Arthur. The series is composed altogether of sedimentary strata, and consists mainly of fine-grained sandstones, which are locally quartzites, and carbonaceous shales or slates, and in small part of cherts and jaspers, beds of carbonate of iron, hematite, and magnetite, conglomerate, and occasional lenses of nonferruginous carbonate in the slates. Except in local instances the rocks have been disturbed very little from the horizontal, the average dip of the strata being in a southeasterly direction at an angle probably not exceeding 5°. Intrusive rocks are abundantly present as sills lying parallel to the stratification, resembling contemporaneous beds, and as vertical dikes, some of which have been observed in continuity with the sills. Faulting is a common occurrence in the Animikie, many scarps being due primarily to this cause.

The Archean shares the coast line with the Animikie and Keweenian from the vicinity of Port Arthur to the eastern end of Nipigon Bay, and beyond this point to the outlet of the lake is the dominant series. This complex consists of two divisions: (1) A great volume of profoundly altered sedimentary and volcanic rocks, characteristically schistose or in the form of massive greenstones, which have suffered intense disturbance, and which correspond to what has been designated the Ontarian system, and (2) immense batholiths of irruptive gneiss and granite, which have invaded the rocks of the Ontarian system from below in the most irregular fashion, corresponding to that division of the Archean which is commonly recognized as Laurentian. These Laurentian rocks exhibit only to a very subordinate extent those evidences of disturbances and deformation which are so abundantly apparent in the schists which they have invaded. The Laurentian gneisses and granites occupy much more of the shore than do the metamorphic and schistose rocks of the Ontarian. Both divisions of the formation are cut by basic dikes, which, as a rule, do not exceed 100 feet in width, and are vertical or nearly so. The Archean forms the basement upon which the Animikie rests in glaring unconformity, the actual superposition being observed at several points, with the Keweenian lying flat on the latter. In many places, however, the Keweenian reposes directly upon the Archean.

Bayley,[183] in 1893, describes actinolite-magnetite schist from the Mesabi range of Minnesota. This rock differs from the corresponding schists of the Penokee series only in that quartz is rare and hematite is absent.

Winchell (H. V.),[184] in 1893, describes the Mesabi iron range of Minnesota. The range extends from the Canadian boundary a little south of west to Mississippi River, a distance of 140 miles or more, but is concealed for a part of this distance by the later gabbro overflow. The succession of the Mesabi is, in descending order:

1. Gabbro unconformably on all the following............Taconic.
2. Black slates, Animikie............Taconic.
3. Greenish siliceous slates and cherts............Taconic.
4. Iron-ore and taconite horizon............Taconic.
5. Quartzite unconformable on 6 and 7............Taconic.
6. Green schists of the Keewatin............Archean.
7. Granite or syenite of the Giants range............Archean.

The granite of the Giants range is bounded on the north by a belt of crystalline mica schists and hornblende schists, and on the south seems to have a direct transition into the green schists of the Keewatin. The green schist has a nearly vertical cleavage. The schists do not always follow the course of the granite range. They are unconformably covered in many places by the quartzite. The quartzite never has a high dip. Near the base it contains pebbles of quartz and granite, as well as jasper and greenstone. This quartzite is correlated with the Pewabic quartzite of Gunflint Lake, the Pokegama quartzite of the Mississippi River, that of Sioux Falls, S. Dak., and that of Baraboo, Wis. Conformable with the quartzite is the iron-ore and taconite horizon. The strata are siliceous and calcareous, and are banded with oxide of iron in beds of variable length and thickness. The ore is sometimes magnetite and sometimes hematite. To the banded jaspery quartzite associated with the ore the term taconite is applied. The greenish siliceous slates or cherts constitute a transition stage between the rocks of the iron horizon and the black slates. There is a considerable mixture of greenish material, apparently of eruptive origin. The greater part of the rock is a red, yellow, black, white, or green chert, sometimes having a thickness of 200 or 300 feet. It often has a peculiar brecciated appearance, having been shattered into angular fragments and recemented by the same amorphous silica. The same fracturing is also visible in the iron ore. The siliceous slates and cherts pass upward into a carbonaceous argillite of great thickness, having a dip varying from the horizontal to 20° to the south or southwest. Locally the dip is as high as 45°, in which case the ore deposits lie close to the green schists. The gabbro flow is over all of the previous strata. The effect of the heat on the molten gabbro was to make the iron ore which already existed in the rocks hard and magnetic. There is good reason to believe that the iron-ore deposits in their present condition have been principally formed since the gabbro overflow. The ore deposits occur as regular beds, which lie in almost their original positions, usually having a dip of less than 30° and passing into the jaspery quartzite or taconite in three directions, and occasionally on all sides.

The theory of Irving as to the origin of the Gogebic ores is partially adopted. The quartzite is impervious to surface infiltration. The ore is regarded as produced by chemical replacement of some mineral, chiefly silica, by oxide of iron. As evidence of this, all stages of the process may be seen. Iron carbonate is found in the Mesabi rocks, but it does not appear in sufficient quantity to permit the assumption that the source of the ore was originally a carbonate. The solvent for the silica was probably carbon dioxide, and its source may have been the atmosphere, the black slates, recently decaying vegetation, or the ore deposits higher up the hill. The silica removed from the location of the iron ores has been added to the grains of quartz in the quartzite, has been deposited as chalcedonic and flinty silica, and has been deposited in cracks and fissures in the slate, which lie at a lower elevation, but stratigraphically above the ore. The source of the iron is believed to have been chemical and mechanical oceanic deposits, which have simply concentrated in the present situation, perhaps from rocks now completely removed by erosion. The water which brought in the iron ore to supply the place of the silica taken away in solution followed the natural drainage courses—either the drainage slopes or the points. The Giants range is regarded as having been uplifted at the time of the gabbro outflows, and to have been caused by them.

GRANT,[185] in 1894, gives a general account of the geology of the Gunflint Lake district. In Tps. 65 and 66 N., Rs. 4, 5, and 6 W., are Keewatin rocks, including the usual types—volcanic tuff, greenstone schists, greenstone, and the Ogishke conglomerate. The Saganaga granite is intrusive in the Keewatin. The more crystalline schists of the district have been called Coutchiching and Vermilion. It appears, however, that these rocks in this area are a more crystalline phase of the Keewatin, and that they owe their crystalline nature to the proximity of intrusive granite.

The iron-bearing rocks of Akeley Lake lie upon the Keewatin greenstone to the north, and on the south are overlain by the great gabbro mass. The belt has a width of 300 to 1,300 feet, and a dip varying from 20° to almost vertical, but averaging 45° to 50°. Where widest it has an average dip of 30°, which would make a maximum thickness of 650 feet. The iron ore is a nontitaniferous magnetite.

The Animikie rocks are little disturbed, except locally, having an average dip of 8° or 10° a little east of south. The Animikie beds are interleaved with diabase sills. These give parallel east-west ridges, the south sides of which are gentle slopes and the north steep mural descents. This topography has led Lawson to the conclusion that the apparently large number of sills are due to monoclinal faulting of fewer layers, but of this there is no evidence. The Animikie strata are divided as follows: An upper or graywacke slate member, 1,900 feet thick, composed of slates and graywackes with fine-grained quartzites and quartz slates; a middle or black slate member, 1,050 feet thick, composed mainly of black slates, apparently carbonaceous, with a fine-grained siliceous and flinty layer at the base 60 feet thick; and a lower or iron-bearing member, composed largely of jaspery, actinolitic, siliceous, and magnetitic slates, usually thinly laminated, and some beds of cherty iron carbonate. The Akeley Lake rocks, first called Pewabic quartzite, are similar to the Gunflint iron-bearing rocks and different from the Pewabic quartzite of the western Mesabi range, and if these iron-bearing rocks are put at the base of the Animikie there seems to be serious objection to regarding them as the basal quartzite and the equivalent of the quartzite of the western

Mesabi range. No true quartzite is found at the base of the Animikie in the Akeley Lake area, but the iron-bearing rocks at Gunflint Lake rest directly upon the Keewatin.

The quartzites of Pigeon Point are lithologically similar to the quartzite at the top of the graywacke slate member and are supposed to be equivalent to it. The igneous rocks are all intrusive. The diabase sills in places have a thickness of 100 feet. They have not been found in contact with nor to extend into the gabbro below. The great Keweenawan gabbro of the district has a varying mineralogical composition, in places being composed almost entirely of feldspar, thus forming anorthosite, and elsewhere being exceedingly rich in olivine. This gabbro includes fragments of the Animikie slates, and was found directly overlying and in contact with the uppermost member of the Animikie, thus showing it to be of post-Animikie age. Associated with the coarse-grained gabbros are finer grained rocks, including gabbros, olivine gabbros, norites, and olivine norites, which have been called muscovado. These are slightly older than the main mass of gabbro, which is seen cutting and including fragments of them.

The acidic eruptive rocks, called augite syenite by Irving, including reddish, hornblendic, granitic rocks, are found cutting the gabbro. In passing toward the granitic rocks, at first a few small acidic dikes are seen. These increase in frequency in approaching the central mass of the granite, and at the edge of the mass apophyses can be traced directly from the granite into the gabbro. The dikes are not finer grained, as a whole or at their edges, than the main mass, thus indicating the heated condition of the gabbro when the dikes were intruded. It is concluded that while the granite is of later date than the gabbro, it is not much later, and was perhaps intruded before the complete solidification of the basic rock.

Culver,[186] in 1894, describes the rocks of Itasca County, Minn. The Pokegama quartzite was found to extend from the north end of Pokegama Lake northeasterly to the rapids of Prairie River. This rock is flat lying, with low southerly or southeasterly dip, and seems to have been bowed into a series of low, flat arches. The lower beds are fine grained, hard, and massive, although broken into cubical blocks. In the upper portions of the quartzite in many places is found a considerable quantity of iron ore. In cross section there are alternately sheets of ore and sheets of quartz. In the hand specimen these quartz layers show no grains. The structure is porous, and the quartz is usually stained red. Both the ore and the quartz layers are exceedingly irregular, and are often interrupted or cut by each other.

The Prairie River granite lies in a belt parallel to the Pokegama quartzite. It contains some bodies of schist, which are taken to indicate that the granite is eruptive. Thrust planes are numerous, and generally have either vertical or very steep dips.

On Big Fork River, a few miles above the mouth of Rice River, diorite was found, and also at Koochiching Falls in Rainy River. Greenstones constitute the chief exposures between Rice River and Big Falls. They comprise beds which are purely eruptive, other beds which are consolidated tuffs, and other phases which it is not possible to place certainly in either class. The mica schists constitute an immense series, extending on Big Fork River from a point 12 miles below Little Falls to within 15 miles of Rainy River. At various places the mica schist is cut by granite. The mica schist gradually becomes veined with a granite, which increases in abundance until granite becomes the predominating rock. The schists are also cut by dikes of greenstone.

ELFTMAN,[187] in 1894, publishes his field notes on northeastern Minnesota. In the region north of Snowbank Lake are found conglomerate, mica schist, sericite schist, argillite, diabase, conglomeratic greenstone, porphyry, augite granite, and hornblende granite. The former of these granites has heretofore been called gray syenite, and the latter red syenite.

On the west shore of Boot Lake, in the SW. ¼ NW. ¼ sec. 21, T. 64 N., R. 8 W., are several large dikes of porphyry cutting the graywacke and schist. In the SW. ¼ NE. ¼ of the same section, on the east side of a long point, dikes of granite are found cutting the conglomerate in all directions and distorting the strata in a very complicated manner. In the conglomerate are bowlders up to 4 feet in diameter of gneiss, slate, diabase, and granite, the last being scarcely distinguishable from the granite which cuts the conglomerate. In some instances a granite dike was found to cut some of the large bowlders of the conglomerate, when the contact between the dike and the granite bowlders could not easily be determined. The exact relations of the hornblende granite and the augite granite to each other, and the relations of the latter to the sedimentaries, are still doubtful. The gray granite has not been found in contact with the schists, argillites, and conglomerates, and it is cut by the red granite, which also cuts the schist. The hornblende schists and mica schists of Snowbank and White Iron lakes grade into argillaceous slates and conglomerates, the schistose character being most fully developed at the contact with the granite.

The Animikie actinolite-magnetite schists are derived from rock containing an original iron carbonate. As the formation thins out toward the east and passes under the gabbro it becomes more crystalline. Near the contact of the gabbro augite and olivine occur intimately associated with the actinolite and magnetite of the Animikie schists. The black slates have been changed into biotite schist in the proximity of the gabbro. These slates disappear before Dunke River is reached, having been removed at the time of the gabbro intrusion. The Pewabic quartzite at the bottom of the Animikie decreases in thickness as Birch Lake is approached from the west, and in the vicinity of Iron Lake disappears entirely. From this locality eastward the iron-bearing rock rests upon the granite. It is concluded that the Pewabic quartzite between Birch Lake and Gunflint Lake belongs to the middle iron-bearing member of the Animikie.

In Tps. 61 and 62 N., Rs. 10 and 11 W., occurs a heavily bedded olivine gabbro. In going from the northern and southern limits of the gabbro toward the center of the area it is noticeable that the ferromagnesian minerals decrease and the feldspar increases in proportion, until in the center of the mass occur numerous knobs and areas, a mile or more in extent, composed of plagioclase rock or anorthosite, which are regarded as segregations. In the center of the mass the rock has greater coarseness of texture, and also more of a stratified appearance, arising from the arrangement of the constituent minerals in bands. The mineral and chemical compositions of the various parts of the formation correspond to the known rules which govern the cooling of liquid magmas, and the whole is regarded as a batholithic intrusion rather than a surface flow.

Red rocks, comprising augite syenite, quartz porphyry, felsite, etc., occur in the vicinity of Greenwood Lake, and were followed to the shores of Lake Superior, making together one prominent group of rocks.

The dark gabbros of Irving, the diabases, and the amygdaloids are placed in another group, called the diabase group. The anorthosites of the coast of Lake Superior, described by Lawson as pre-Keeweenawan, and newly discovered masses back from the coast, are found to be detached blocks from the great gabbro mass inclosed in and underlain by the black gabbro, as previously held by Irving and Winchell. The latter rock is considered as the effusive equivalent of the great basal gabbro. After the aggregations of feldspar had separated from the gabbro magma, and were floating around in it, they were ejected in portions of the unsolidified magma, and, being lighter than it, floated near the surface, and are found only near the top of the first outburst of lava or black gabbro. Later, when the rock was somewhat eroded, the feldspar knobs projected above the surrounding rocks, and later were covered by the flows of the red rock group. Therefore the conclusion of Lawson that the anorthosite forms a pre-Keweenawan terrane is rendered valueless.

In chronological order the Keweenawan of the north shore of Lake Superior can be divided into gabbro, diabase, red rocks, and later dikes.

SPURR,[188] in 1894, discusses the stratigraphic position of the Thompson slates of northeastern Minnesota. These have heretofore been correlated with the Animikie slates. However, almost every phase of slate of the Thompson series can be duplicated by the less-altered phases of the Keewatin schists of the Mesabi range. In the vicinity of Mississippi River the Thompson series becomes partly crystalline, being changed into sericitic, micaceous, hornblendic, staurolitic, or garnetiferous schists which correspond exactly with the green schists of the Keewatin. The cleavage of the Thompson series marks a distinctively pre-Animikie disturbance. The trend of the cleavage corresponds with that of the schistosity of the Keewatin of the Mesabi range, and it is thought that the two were developed at the same time. The Thompson series has undergone considerable folding, and in this respect also more resembles the Keewatin than the Animikie slates, which are in an undisturbed condition. The Thompson series is therefore regarded as unconformably below the Animikie, and is provisionally correlated with the Keewatin.

SPURR,[189] in 1894, gives an account of the rocks of the Mesabi district, and particularly of the iron-bearing rocks.

The oldest formation of the district is the Keewatin, the most common rock of which is green schist, but associated with this, especially near the granites, are hornblende schists and mica schists. The schists have a regional cleavage, which is nearly uniform in trend, about N. 70° E., and nearly vertical. Next in age to the Keewatin schists is the hornblende granite of the Giants range. This range has an average width of about 10 miles, and its direction is the same as that of the schistosity of the Keewatin rocks. The granite is intrusive in the schists, as shown by numerous fragments embedded in it, by stringers of the granite in the schists, and by the metamorphism of the schists adjacent to the granite.

Unconformably upon the former is the Animikie series. The Animikie series has no marked folding, slaty cleavage, or schistose structure. The rocks of the series are in a gentle southern monocline, in a direction perhaps 10° or 15° east of south. This monocline has gentle undulations, with axes parallel to its dip, and in the Virginia area has been faulted. The amount of disturbance is greater adjacent to the central part of the district, where are found the Keweenawan rocks. It is probable that the weight of the Keweenawan rocks has produced a sinking in the area south of the Animikie, and that this has produced the tilting. The Animikie series may be divided into three chief members—the Pewabic quartzite, the iron-bearing member, and the upper slates. The Pewabic quartzite is a fragmental rock indurated by the enlargement of quartz grains. It occasionally passes into a fine-grained conglomerate. The iron-bearing member is composed of peculiar rocks, presenting no resemblance to the Pewabic quartzite or to the upper slate. The upper slates are of great thickness, and have at their base an impure limestone, often dolomitized or sideritized.

The part of the iron-bearing member which extends from Pokegama Falls to Embarrass Lake is called the Western Mesabi Range; the part from Embarrass Lake to Gunflint Lake, the Eastern Mesabi Range, and the part from Gunflint Lake east, the International Boundary area. The description of the iron-bearing member below applies to the western part of the district. It has a thickness varying from 500 to 1,000 feet, with an average of about 800 feet. The dip varies from less than 10° to as much as 30°, and the width of the formation varies correspondingly from 2 or 3 miles to less than half a mile, the average width being 1 mile and the average dip 10°. Resting upon the iron-bearing member is a great thickness of fine-grained slates, at the base of which is locally an impure dolomitic limestone. When this limestone is present the contact between the iron-bearing member and the upper slate can not be distinctly located.

The least-altered phase of the iron-bearing member is a rock called taconite, which consits of a background of cryptocrystalline, phenocrystalline, and chalcedonic silica, in which are numerous granules. These are composed of glauconite, siderite, hematite, magnetite, limonite, and cryptocrystalline silica, in the very freshest phase, the two former being predominant. The granules in one of these fresher phases showed by analyses about 35 per cent of siderite and 65 per cent of glauconite, or about 22 per cent of ferrous oxide in the form of siderite, and about 10 per cent of ferrous and ferric oxide, two-thirds being the former in the glauconite. Other analyses gave similar results. Analyses showed a very little calcium and magnesium. In the freshest phase found were seen, in thin section, probably detrital original grains of carbonate, recognized by their cleavage as calcite or dolomite. From the taconite, by a complicated series of metasomatic changes, there have developed cherts and jaspers, which are sideritic, hematitic, magnetitic, or actinolitic, or two or more of these combined. During the process the chert and iron oxides were largely concentrated in alternating bands. The cherts and jaspers are in numerous places concretionary and brecciated. Many of them have a prismatic jointing and horizontal parting.

These transformations were caused by downward-percolating waters, carrying as the chief agents oxygen and carbonic acid, and as subordinate agents sulphuric acid and alkalies. In the changes from glauconite and siderite to the oxides there was an important shrinkage of the mass, and this has resulted in the brecciation, prismatic jointing, horizontal parting, and banding. The prismatic jointing is analogous in its formation to the shrinkage of basaltic columns of lava. The horizontal parting is caused by a later shrinkage along the least diameters of the columns formed by the prismatic jointing. The banding is due to the removal of silica and the entrance of iron along the parting.

The ore deposits rest upon the Pewabic quartzite, or upon the hard and little altered iron-bearing rock, in areas of especial weakness or disturbance, as (1) actual fault lines, (2) incipient fault lines, (3) apices of anticlinal folds, and the troughs of synclines. These are places of fracture and where abundant waters were converged, often wide areas, and therefore places where large quantities of iron were supplied. The downward-percolating water, taking iron carbonate in solution, precipitated the iron as oxide in those places where there was an abundance of oxygen, and at the same time took the silica in solution, thus forming the ore bodies. Between those of the largest size and the small local concentrations there are all gradations. The larger deposits of ore occur where they are protected from glacial erosion on the north by a hard ridge of the Keewatin rocks, and especially when the hard rocks give slight elevations on either side, so as to present a basin-like depression.

The glauconite in origin is believed to be the same as modern glauconites—that is, it has developed within Foraminifera and other minute shells, as a result of a reaction between the organic matter within the shells and fine ferriferous clay. As the formation contains only a small quantity of ordinary fragmental quartz grains, it formed in water at a depth beyond which much of these materials was deposited. As its upper horizon grades into limestone this indicates a further subsidence of the area, so that the distance from the shore line became so great that very little mechanical detritus was furnished, and the deposit was made up of calcareous matter.

In the eastern Mesabi district the Animikie strata are pierced and intermingled with the northern border of the Keweenawan rocks, so that their normal attitude is often much disturbed. With this change the iron of the iron-bearing member becomes largely magnetic and the silica hard and crystalline. It is concluded that the iron before Keweenawan time was here in the state of sesquioxide, and that the heat of the igneous Keweenawan rocks and the disturbances of the Animikie series produced by them are the causes of the change of the sesquioxide of iron to its magnetic form. Thus the normal process of decomposition and concentration was brought to a close, and this probably explains the poverty of this part of the district in large ore deposits.

At the base of the Cretaceous are ferriferous detrital deposits derived from the Animikie. A study of these indicates that the metasomatic processes had gone far before Cretaceous time, although they have since continued to the present time.

WINCHELL (N. H.),[190] in 1895, discusses the origin of the Archean greenstones. The great bulk of them are pyroclastic. They were distributed and somewhat stratified by the waters of the ocean into which the material fell. Evidence of their arrangement by water is seen in their very general stratiform structure, which can only be explained by the action of water. This structure stands vertical or nearly so. These greenstones constitute a distinct terrane, forming the latest portion of the Keewatin, at the top of the Fundamental Complex of the Lake Superior region. Below the greenstones are found chloritic slates and schists, chloritic schists, clay slates, graywackes, conglomerates, quartzites, novaculites, and jaspilites. The thickness of the greenstones in Minnesota exceeds that of any other Archean terrane. The Keewatin passes gradually down into crystalline mica schists or hornblende schists, and finally into acidic gneiss.

WINCHELL (H. V.) and GRANT,[191] in 1895, give a preliminary account of the Rainy Lake gold region. Following Lawson, they separate the rocks there found into four distinct groups. These are, beginning with the lowest: (1) Laurentian, composed of granites and granitoid gneisses and allied rocks; (2) Coutchiching, composed of mica schists grading into fine-grained gneisses; (3) Keewatin, composed of hornblendic, greenish, and sericitic schists, conglomerates, graywackes, etc.; (4) diabase dikes, more recent than and cutting all the others. The Coutchiching mica schists have in many places rapid alternations in bands from an inch to several feet in width of slightly different mineralogical composition, structure, or color. The position of these bands gives the strike and dip of the rock, and when they are lacking the schistose structure is taken as giving the strike and dip, as this seems to be parallel with the banding when the two are seen together. While an unconformity between the two is not proved, it seems quite probable, on account of basal conglomerate beds in places in the Keewatin resting on the Coutchiching.

WINCHELL (H. V.),[192] in 1885, gives a brief sketch of the iron ranges of Minnesota. Along the north side of the Mesabi range is a ridge of Archean syenite and granite, flanked on both sides by crystalline and semicrystalline schists. This ridge is called the Giants range. On the south side of the Giants range, lying at times nearly up to its summit, are the outcropping edges of Taconic or Upper Huronian strata, which overlie unconformably the syenites and schists. These are in turn overlapped to the south by eruptive rocks of Keweenawan age and by Cretaceous sediments. The ore is soft hematite, which lies at low angles from the horizontal, usually covered merely by drift.

The geology of the Vermilion range is not yet understood. The iron ores are solid and massive, except at the Chandler mine, where they are brecciated and occur in steeply inclined lenses between walls of schist, extending to an indefinite depth.

Elftman,[193] in 1895, finds that the great gabbro of northeastern Minnesota has a rude arrangement of the rock in parallel layers similar to the layers of sedimentary rocks. This structure usually dips to the south. It does not depend upon the differentiation of the mineral components of the rocks, but seemingly is due to secondary causes which acted upon the rock after it had solidified. This sheeted structure is a common phenomenon along the northern limits of the mass. The gabbro has also a banded structure due to the parallel arrangement of the mineral constituents. The bands are not regularly arranged, appearing and disappearing in a manner which shows them to be not independent of the secondary causes. This structure is present to a marked degree in the central portion of the gabbro.

Large feldspar masses occur in the gabbro in the southeastern parts of T. 61 N., Rs. 10 and 11 W. The mass in the latter township has a marked banding. The line of division between the feldspar masses and the normal rock is sharp in the field and in the hand specimen. Both are, however, regarded as differentiations from the same magma.

In the southern part of T. 62 N., R. 10 W., the eastern part of T. 61 N., R. 11 W., the greater part of T. 61 N., R. 10 W., and in adjacent townships is a considerable area of dark, reddish-colored olivine gabbro or troctolite, which has both a sheeted and a banded appearance. This rock and the normal gabbro have not been seen in contact, but wherever they closely approach each other, often within a few feet, both preserve their characteristic structure and there is no sign of the transition of the one into the other. The olivine rock appears to be above the ordinary gabbro.

Smyth and Finlay,[194] in 1895, describe the western part of the Vermilion range. The sedimentary rocks fall into two divisions. The older is a fragmental slate formation, while the younger is an iron-bearing formation lithologically identical with certain phases of the lower iron-bearing formation of the Marquette district. To all appearances it is devoid of clastic material. It is believed, from analogies with other iron-bearing districts of the Lake Superior region, that the jasper of the Vermilion district is derived from a cherty iron carbonate or from a glauconitic greensand, or both. However, as the jasper is a final product of the alterations, it is not possible to show this.

Intrusive igneous rocks are very abundant, cutting or being interleaved with the sedimentary rocks in masses running from the thickness of a knife blade to those 100 feet across. In quantity the igneous rocks exceed, perhaps several times, the sedimentary rocks. The oldest igneous rocks are greenstones. These vary from massive to schistose, and even to conglomerate-breccias. The acidic rocks were intruded later than the basic rocks. They were originally for the most part quartz porphyries, but these have been extensively changed to sericite schists and conglomerate-breccias, and to rocks intermediate between these and the original form. Within the larger masses of the igneous rocks, both basic and acidic, are frequently included fragments from both the slate and iron formations, from those of small size to masses more than 100 feet long.

The conglomerate-breccias are of dynamic origin. The first step in the development of the breccias was the formation of two intersecting sets of planes of fracture, dividing the originally massive rocks into roughly rhomboidal blocks. Their further development depended on continued movement between these blocks under pressure, which resulted in enlarging the shearing zones at the surfaces of contact and rounding the angles. The slate and jasper inclusions originally plucked off from the rocks which the porphyries and greenstones invaded, shared, of course, the subsequent history of their captors. The fact that the jasper inclusions are frequently rounded, while those of slate are not, is explained by the difference in the elasticity of the two rocks. The slate inclusions readily yielded and finally took a permanent set under the deforming forces, while the harder and more rigid jasper, in fragments of limited size and diverse orientation, behaved like the inclosing porphyry. The boundaries of the inclusions were generally the surfaces along which rupture took place, although, as has already been said, jasper in a few instances is found partly held in porphyry inclusions.

As to structure, the main slate area is anticlinal; both north and south of this area the jasper succeeds the slates. The southern jasper continues in a complex syncline, and south of this is found the northern limb of another anticline of slates, the southern limb not being exposed. Still farther south is the jasper of Lee and Tower hills, which appears to form the southern and western edges of a complex syncline. All of these folds pitch toward the east.

The ore deposits are found to conform in occurrence to the laws worked out by Van Hise in reference to other districts of the Lake Superior region; that is, (1) they occur for the most part in pitching troughs with impervious basements. Usually this impervious basement is one or more of the different varieties of the eruptive rocks. (2) They are secondary concentrations produced by downward-percolating waters, the silica being leached out and the iron ore deposited.

Winchell (Alexander),[195] in 1897, gives a detailed petrographical description of the Koochiching granite occurring on the north boundary of Minnesota, about 2 miles west of Rainy Lake. The rock is a biotite-hornblende granite of eruptive origin, and is assigned to the Laurentian.

WINCHELL (N. H.),[196] in 1897, presents some additional points on the geology of northeastern Minnesota.

The Laurentian includes, in Minnesota, an acidic crystalline schist of sedimentary origin, and a massive igneous rock, although the igneous rock is younger than the crystalline schist portion and should have a different designation. The conclusions reached are that (1) the sedimentary Laurentian is a crystalline condition of sedimentary strata, which are conformably a portion of the sedimentary schists; (2) the igneous Laurentian is the result of a more intense metamorphism, carried even to fusion of some strata. These conclusions result particularly from the study of a section from Tower northward, through Vermilion Lake, and of an area on the west side of Outlet Bay, in the corners of secs. 13, 14, 21, and 32, T. 63 N., R. 17 W., and along the shore for one-half mile westward.

It is evident that the Stuntz conglomerate on the south shore of Vermilion Lake is a true water-deposited conglomerate, of the same formation as the slates and graywackes of the district, the conglomerate grading into the quartzite and graywacke, and this into argillaceous slate. Furthermore, as supposed by Van Hise, the conglomerate lies unconformably on the iron-bearing formation and contains very numerous fragments of jaspilite. The position of this unconformity, whether at the base of the Taconic or lower, is not ascertained.

The nature and position of the conglomerate in the valley of the Puckwunge, a small stream entering Pigeon River north of Grand Portage, are discussed. This conglomerate is overlain by igneous rocks resembling the traps of the Keweenawan. The subjacent formation can not be certainly determined, but in the same locality, at a lower level, is a slate rock, called the Puckwunge slate, which was followed for some distance north and east, and which is probably an upper member of the Animikie, not before individualized. The conglomerate contains quartzite pebbles, which are referable to the quartzites of the Animikie, farther north. It may be inferred that this is the basal conglomerate of Keweenawan, which has been identified up to Grand Portage Island and at intervals along the Lake Superior coast from Baptism River to near Beaver Bay.

BERKEY, in 1897 and 1898, describes the geology of the St. Croix Dalles. See summary in section 2, northern Wisconsin, page 192.

WINCHELL (N. H.),[197] in 1898, attempts to explain the origin of the Archean igneous rocks. From field evidence and petrographic discriminations and associations, it is believed that the alkaline magma from which the igneous rocks were derived is the result of aqueo-igneous fusion of the fragmentals of the Archean itself; that when deeply buried, under heat and pressure, the Archean clastics were rendered plastic, penetrating openings in the adjacent and superjacent strata; and that when the plastic mass was not moved from its place it was simply recrystallized in situ.

The clastic rocks must have been derived from the basal greenstone, which is considered representative of the original crust of the earth. The presence in such clastics of sufficient potassa and silica to yield upon fusion the granitic magmas is explained on the hypothesis that they must have come from the waters depositing the fragmentals, and primarily from the atmosphere, in its condition normal to the Archean age, just following the congealing of the first crust.

While numerous instances of such transition from clastic to igneous rock have been noted in Minnesota, there has been a careful study of but one. That was the case of the granite and porphyry which intrude the clastics at Kekequabic Lake.

WINCHELL (N. H.),[198] in 1898, discusses some resemblances between the Archean of Minnesota and of Finland. The succession in northeastern Minnesota, as made out largely from field work done in 1897, is as follows, in descending order:

1. Granitic intrusion, cutting and metamorphosing the earlier schists and fragmentals. This rock is seen about Snowbank Lake and Moose Lake, about the western confine of Disappointment Lake, and at Kekequabic Lake.

2. Upper Keewatin, consisting of conglomerates (at Stuntz Island and at Saganaga and Ogishkie Muncie lakes), sericitic schists, quartzose and micaceous schists, graywackes, clay slates, chloritic schists, and porphyroids. The mica schists, embracing many conspicuous bowlder-like forms on the weathered surfaces, are to be seen about Moose Lake and southeast of Snowbank Lake, about Disappointment Lake, Kekequabic Lake, and eastward to Zeta Lake.

3. Granitic intrusion, chiefly represented by the granite of Saganaga Lake, where the Upper Keewatin lies unconformably upon it. It is also seen a little west of Ely and on Kawishiwi River. At West Seagull Lake this granite cuts older greenstones and green schists.

4. Lower Keewatin or Kawishiwin, mainly a greenstone formation, both massive and fragmental, constituting the oldest formation in the State. When stratified it consists of basic tuffs, agglomerates, and green stratified schists and "greenwackes." It contains the banded jaspilites and iron ores at Vermilion Lake. Where cut by granite and porphyry (1) these rocks are converted to mica schist and banded gneiss.

Unconformably above all these is the Animikie formation, of Taconic age, the base of the Paleozoic.

Nos. 1, 2, and 3, above, are paralleled in Finland by similar rocks in similar order, as described by Sederholm. Rocks corresponding to No. 4, the Lower Keewatin, seem to be wanting, or are seen only as inclusions in the next younger granite.

It is probable that the divisions above detailed for Minnesota and Finland are wholly embraced in the lower division of the Canadian Laurentian, i. e., in the Ottawa gneiss, and that they have not yet been noted in Canada. The fundamental gneiss of Canada is, therefore, not the bottom of the geological series, but is largely a sedimentary series derived from an older series, this older series being in part at least a greenstone, as indicated by the stratigraphic succession in Minnesota.

Winchell (N. H.),[199] in 1898, discusses the Archean greenstones of Minnesota, which he considers the oldest known rocks, representing the original crust of the earth. The greenstones are divisible into two parts, one igneous and the other clastic, the latter succeeding the former with a confused and apparently sometimes conformable superposition, somewhat as surface eruptive rocks might be superposed, in the presence of oceanic action, upon a massive of the same nature at the same place. The clastic portions of the greenstones vary to more siliceous rocks, constituting great thicknesses of graywackes, phyllites, and conglomerates, and as such have been converted by widespread metamorphism into mica schists and gneisses.

As the Laurentian gneisses and granites cut the schists and sedimentary gneisses they are also younger than the bottom greenstones.

The metamorphic schists and gneisses seem to be representative of the sedimentary portion of the Lower Laurentian of Canada, while the igneous granite and gneisses are as plainly a general parallel of the igneous portion of that series. It follows, therefore, that the Canadian Laurentian is, as a whole, of later date than the greenstones, if the succession is the same as in the Northwest, and that the greenstones should be considered the bottom rock of the geological scale.

Winchell (N. H.),[200] in 1898, discusses the significance of the fragmental eruptive débris at Taylors Falls, Minn. This has heretofore been regarded as a conglomerate resting unconformably upon the Keweenawan. As a result of recent field work by C. P. Berkey, it is believed that this conglomerate may be separated into two conglomerates—an upper one at the base of the upper division of the Cambrian and a lower one at the base of the lower division. The latter would come within the Keweenawan, as this term is used by Irving and other writers, and would separate this series into two parts.[a] The later conglomerate rests directly upon the earlier one, leading to the previous confusion of the true relations. Similar conglomerates

[a] In a recent paper, summarized on p. 192, Berkey (Am. Geologist, vol. 20, 1897, p. 381) takes the view that the lower conglomerate is a flow breccia of the igneous rocks.

found in the Keweenawan at several points between Duluth and Grand Portage have led to the conclusion that the Keweenawan may be divided into two great series, separated by conglomerate and quartzite which reach a thickness of several hundred feet. The lower series has been included in the Norian, and the upper series, comprising the sedimentaries and the eruptives above them, has been called Keweenawan, the Keweenawan forming the lower division of the Cambrian.

Grant,[201] in 1898, sketches the geology of the eastern end of the Mesabi iron range in Minnesota, including T. 64 N., Rs. 3 and 4 W., and parts of Rs. 2 and 5 W., with some adjacent portions of Ontario. The rocks can be separated into three divisions. The chief one of these is the Animikie series, containing the iron-bearing rocks of the Mesabi range. Older than the Animikie is a series of granites, greenstones both massive and schistose, conglomerates, slates, and other clastic rocks, called the pre-Animikie. Younger than the Animikie are some diabase sills and the great gabbro mass of northeastern Minnesota.

Of the pre-Animikie rocks, the greenstones and clastic rocks have been called Keewatin. As the greenstones are usually associated with the Mesabi iron-bearing rocks, these alone of the Keewatin rocks are described. They lie to the north of the iron-bearing rocks, in T. 65 N., R. 5 W., and extend eastward to the center of T. 65 N., R. 4 W., where they disappear under the Animikie strata. In general the greenstones are at present diorites; originally some were certainly diabases, others were of the nature of andesites, and a large part were diorites, or possibly gabbros. At places, especially along the east side of sec. 27, T. 65 N., R. 5 W., the greenstones contain angular and subangular fragments of rock almost like themselves, and some may be regarded as composed of fragmental volcanic rocks. Associated with the greenstones, especially in secs. 22, 23, and 24, T. 65 N., R. 5 W., are small masses of more acidic rocks, quartz porphyries and quartzless porphyries, which are probably younger than the greenstones.

The pre-Animikie granite has its typical development on the shores of Saganaga Lake. In a number of places it may be seen in intrusive relations with the greenstone. A quarter of a mile south of the northeast corner of sec. 23, T. 65 N., R. 5 W., many granite dikes cutting the greenstone are seen, and on the south shore of West Seagull Lake granite dikes of the same nature as the immediately adjacent main mass of Saganaga granite are seen cutting the greenstone. Both granite and greenstone are cut by another series of finer grained, more acidic granite dikes.

The Animikie rocks rest unconformably upon the pre-Animikie rocks, and usually on the southern slope of the Giants range, which is composed essentially of granite. The strike is approximately east-northeast, and the dip in general about 10° east of south. The thickness varies from a knife edge to 4,000 feet. The Animikie is separable into four conformable divisions: (1) the lower or quartzite member, called the Pewabic quartzite; (2) the iron-bearing or taconite member; (3) the black slate member; (4) the graywacke slate member.

(1) The quartzite member is well developed in Itasca County, but disappears before reaching the eastern side of St. Louis County.

(2) The rocks of the iron-bearing member are similar to those in St. Louis County on the western end of the range, described by Spurr.[a] They differ, however, in two features. They are more completely crystalline, and the iron is magnetite instead of hematite. The rocks consist chiefly of jaspers, amphibole (grünerite) schists, greenish siliceous slates, cherts, cherty carbonates, and magnetite slates. It is believed that these rocks were originally glauconitic greensands; that the ore has been derived from the iron in the glauconite, and that the ore bodies result from concentration and replacement. In this part of the Mesabi range no ore bodies have yet been found which are at the same time both rich enough and large enough for profitable mining, although vast quantities of magnetite ore occur at or near the surface.

The dip of this formation varies from an average of 45° to 50° on the west to less than 15° on the east, and the thickness varies from 650 feet or less on the west to 900 feet on the east.

(3) The black slate is essentially a fine-grained, black, more or less siliceous, apparently carbonaceous slate.

(4) The graywacke slate member is composed of black to gray slates and fine graywackes, with some flinty slates; the upper part shows coarser detrital material, and the highest beds seen are fine-grained quartzites and quartz slates. This member is well exposed on the south shore of Loon Lake.

Associated with all of the strata of the Animikie are diabase sills, and bounding the Animikie rocks on the south is the great gabbro mass. These are igneous rocks of later date than the Animikie. Near the contact with the gabbro the Animikie rocks show marked metamorphism and usually complete recrystallization. The gabbro varies from a nearly pure plagioclase rock to titaniferous magnetite.

The pre-Animikie rocks here described, according to the nomenclature used by the United States Geological Survey, belong to the Lower Huronian series of the Algonkian system, and probably also in part to the older Archean or Basement Complex; the Animikie is regarded as the equivalent of the Upper Huronian series of the Algonkian, and the gabbro as the lower part of the Keweenawan series of the Algonkian.

[a] Bull. Geol. and Nat. Hist. Survey Minnesota, vol. 10, 1894.

WINCHELL (N. H.),[202] in 1899, discusses the general structural geology of northeastern Minnesota. The ancient rocks of this area he places in two main systems, the Archean and the Taconic. The former is further subdivided into the Upper and Lower Keewatin, separated from each other by an unconformity. The Pewabic quartzite also is placed with the Keewatin, but is not assigned to either of the main divisions. Overlying the Archean with strong unconformity is the Taconic, represented by Animikie and Keweenawan rocks, these divisions being supposed to represent respectively the Lower and Middle Cambrian of other parts of the country. The Coutchiching and Laurentian rocks before mapped as separate formations are now included within the Keewatin.

The Lower Keewatin comprises greenstone, with associated surface volcanics which are both subaerial and subaqueous, argyllitic slates, siliceous schists, quartzites, arkoses, "greenwackes," iron ores, and marble.

The greenstone, designated the Kawishiwin, is the oldest known rock in the State, and is supposed to represent a portion of the original crust of the earth. With its associated volcanic rocks it occurs in two main belts. The southern belt begins in the vicinity of Gunflint Lake and extends westward by way of Gobbemichigamma Lake, the Kawishiwi River, and White Iron Lake, to Tower, and indefinitely westward. The northern belt of greenstone enters the State from Hunters Island, appearing conspicuously at the south side of Basswood Lake. At Pipestone Rapids and Fall Lake it widens southward and apparently unites at the surface with the southern belt, the overlying Upper Keewatin being absent for a distince of a few miles. But farther west it is again divided by the Stuntz conglomerate, the northern arm running to the north of Vermilion Lake, west of which its extension is unknown, and the southern one running south of the lake.

The fragmental stratified rocks of the Lower Keewatin are most important toward the western part of the area of exposure of crystalline rocks. They occupy a wide area south, west, and north of Tower. The iron ores of Tower and Ely, on the Vermilion iron range, occur in the upper part of the Lower Keewatin. It is probable that the immediately inclosing rock is a sedimentary one, although composed of the elements of a basic eruptive. The sediments extend south to the Giants range of granite, where they are metamorphosed to mica schists by the granite. Toward the west they extend as far as the Mississippi River and its northern tributaries and across the Bowstring, although the drift prevents the delimitation of the belt. To the northwest they extend toward Rainy Lake, in this direction being converted into mica schists and gneisses by the intrusion of granite; in unmodified form they are found at one point only on Rainy Lake. These fragmental rocks of the Lower Keewatin doubtless also underlie most of the central and southwestern part of the State as far as the Minnesota River. Here they dip beneath the later formations in the southwestern portion of the State, and probably occupy a wide patch in South Dakota. South of the Giants range they occur also, but as they are covered by the gabbro and Animikie toward the east and the drift deposits of the St. Louis Valley toward the west their geographic boundaries are mostly unknown. They appear in the central and western portions of Carlton County, where their line of separation from the Upper Keewatin is obscure, and in the central and western portions of Morrison County. The Lower Keewatin marble is seen at Lake Ogishke-Muncie and at Pike Rapids on the Mississippi.

The Lower Keewatin was terminated by a period of extensive folding and intrusions of granite and basic rocks.

The Pewabic quartzite belongs with the Keewatin, but whether to the Lower or Upper Keewatin is not known. This formation includes altered quartzites and iron ores between the granite and gabbro in the immediate vicinity of Birch Lake, and small patches of similar rocks in sec. 30, T. 62 N., R. 10 W.; on the south shore of Disappointment Lake; on the north shore of Fraser Lake; on the south shore of Gabbemichigamma; at Akley Lake, forming the so-called Akley Lake series extending from the west side of sec. 34, T. 65 N., R. 5 W., to the eastern part of sec. 27, T. 65 N., R. 4 W.

The Upper Keewatin occurs in troughs in the Lower Keewatin, and particularly in one main trough the axis of which is traceable from Vermilion Lake to Saganaga Lake. The northern arm of this syncline, consisting of granites, gneisses, associated mica schists, and in some places earlier greenstones, extends from the northern part of Vermilion Lake through Basswood Lake to the northern side of Hunters Island. The southern arm, consisting of Lower Keewatin green schists and other schists, penetrated by the granite of the Giants range, extends from Pokegama Falls on the southwest toward the northeast, until cut out by the encroachment of the gabbro from the south. The Upper Keewatin consists very largely of conglomerates, but also includes graywackes, argillites, quartzites, and jaspilites, in general coarser than those of the Lower Keewatin. Volcanic rocks are less important than in the Lower Keewatin, although still present. There is no general order of succession in the Upper Keewatin, except that it is in general conglomeratic at the bottom.

After Upper Keewatin time both the Lower and the Upper Keewatin were subjected to another folding, the axis of which had a general parallelism with the earlier folding, with the result that the Upper Keewatin lies in narrow synclines in the Lower Keewatin and in places is nearly or quite vertical.

Associated with the Keewatin rocks are granites of at least two periods of intrusion, one later than the Lower Keewatin and one later than the Upper Keewatin. The later granite is believed to be represented by the higher parts of the Giants range and the Snowbank Lake granite. The earlier granite is represented by the granites at Kekequabic Lake, Saganaga Lake, Basswood Lake, Burntside Lake, Vermilion Lake, Lac la Croix, and Kabetogoma Lake. The origin of the granite is discussed.

The Taconic is unconformably above the Keewatin rocks. It comprises the Animikie and Keweenawan divisions.

The Animikie rocks enter the State at Pigeon Point and run westward along the international boundary to the eastern part of secs. 22 and 27, T. 65 N., R. 4 W. They reappear again southwestward from Birch Lake, on the northwest side of the gabbro mass, and thence continue along the south side of the Giants range, constituting the Mesabi iron series, to Pokegama Falls. The higher parts of the Animikie are best developed toward the east, while the lower parts are best developed toward the west.

The Animikie rocks comprise the Pokegama quartzite, Mesabi iron-bearing formation, and some limestone and slate, all strictly conformable with one another. The thickness is several hundred feet, sometimes reaching nearly 1,000 feet. The dip of the series is uniformly 8° to 12°.

The iron-bearing formation and the Pokegama quartzite constitute the base of the formation. The quartzite in places is beneath the iron formation; in other places it is in the same horizon; and in still others is above the iron formation. Commonly the base of the Animikie is marked by a conglomerate, containing débris from the underlying Keewatin rocks. This is a narrow horizon which soon graduates upward into a quartzite known as the Pokegama quartzite, from its typical development near Pokegama Falls on Mississippi River. The thickness of the quartzite is not known to exceed 50 feet, and is sometimes less than 25 feet.

Above the quartzite, or in alternating beds with it or below it, appears the iron-bearing or taconite member of the Animikie, which contains the iron-ore deposits of the Mesabi iron range. The ore is usually hematite in the western part of the range and magnetite in the eastern part. It was previously supposed to have been derived from the alteration of a greenish glauconitic sand rock; but later work has seemed to show that the greensand is a volcanic sand, and that the so-called taconitic rock itself has resulted from igneous forces. This is accounted for by supposing a chain of active volcanoes to have existed where the Mesabi iron range is now found. These volcanoes yielded flows and ejectamenta to the adjacent waters, which have been modified into the various phases of the iron formation now seen.

This volcanic epoch may have a deep-seated connection with the Cabotian or lower division of the Keweenawan (described later).

Above the iron-bearing member is an impure dark-colored limestone a few feet in thickness, not exceeding 20. It extends apparently the whole length of the Mesabi range, but has been identified in two places only—sec. 7, T. 58 N., R. 17 W., and, doubtfully, on the shores of Gunflint Lake. This limestone may be regarded as the basal horizon of the next overlying rock.

The black slate is probably several thousand feet in thickness and constitutes the bulk of the Animikie. In the neighborhood of Gunflint Lake it has been divided by Grant into a lower black slate division and an upper graywacke slate division, both of which members are interleaved with diabase sills.

In the Indian reservation at Grand Portage and at various places along the Grand Portage trail is a graywacke which is supposed to overlie the black slate member, but its extent and stratigraphic position have not been satisfactorily established.

The top of the Animikie has not been identified. The first recognizable datum plane after the close of the Animikie is the Puckwunge conglomerate, supposed to be the fragmental base of the Keweenawan.

At one or two places southwestward from Birch Lake, at Little Falls on Mississippi River, and in Morrison County the Animikie has been converted into a mica schist.

The age of the Animikie is believed to be Lower Cambrian for the following reasons: It graduates upward into Upper Cambrian rocks, as seen on the south side of Lake Superior. The derivation of the iron ores from a glauconitic greensand indicates that large quantities of foraminiferal organisms once lived in the Animikie ocean, and Matthew has shown the existence of foraminiferal organisms associated with the iron ore in the St. Johns group of New Brunswick. Further, the Animikie has a uniformly low dip, while the lower strata are all highly tilted. There must therefore have been a great lapse of time between the deposition of the two series.

The Puckwunge conglomerate is taken to be the fragmental base of the Keweenawan, although certain igneous rocks which antedate it and which perhaps are contemporaneous with the upper portions of the Animikie are also called Keweenawan. The conglomerate is found at Grand Portage Island, at Isle Royal, on Baptism River, at Little Marais, on Manitou River, at the deep well at Short Line Park near Duluth, and at New Ulm.

Above this conglomerate are conglomerates and sandstones of Keweenawan age which are stratified with lavas of diabasic nature. Still higher up the eruptive rocks become less in quantity and the fragmental rock is a sandstone, known as the Hinckley sandstone, quarried in the gorge of the Kettle River in Pine County. This in turn grades up into typical Upper Cambrian sandstones of the St. Croix Valley. The term Potsdam is restricted to the Puckwunge conglomerate and the hardened quartzites immediately overlying it, represented by the Sioux quartzite, the Baraboo and Barron County quartzites of Wisconsin, the quartzite at Grand Portage Island and west of Grand Portage village, the New Ulm quartzite in Cottonwood County, and the quartzite in Pipestone County.

The igneous rocks of the Keweenawan vary in age from late Animikie time to the close of the Keweenawan. They are divided into two groups, the Cabotian or Lower Keweenawan, and the Manitou or Upper Keweenawan.

The Cabotian division includes gabbro and contemporaneous red rock and their surface lavas, and all other dikes and sills which are associated with, but are younger than, the Animikie clastic rocks and which are older than the Puckwunge conglomerate. The lower member of the Cabotian is the gabbro, which covers an enormous area. It extends on the east to East Greenwood Lake, in T. 64 N., R. 2 E. On the north it is bounded by the Animikie strata of the Mesabi iron range. Its westernmost exposure is in the vicinity of Short Line Park, Duluth. The southern limit is irregular, swinging from East Greenwood Lake in a zigzag manner through T. 63 N., R. 1 W.; T. 62 N., R. 2 W.; T. 62 N., R. 4 W.; T. 60 N., R. 6 W.; T. 60 N., R. 7 W.; T. 58 N., R. 10 W., and T. 55 N., R. 11 W., to Duluth.

Along the northern and northwestern sides of the great gabbro mass the gabbro is plainly intrusive on the older formations, Animikie and Keewatin.

From the northern border of the gabbro many sills offshoot and penetrate the Animikie strata parallel to the bedding. These are known as the Logan sills.

Near its contact with the underlying rocks, both the Animikie and the Keewatin series, there are various altered rocks which can be connected in places with the gabbro and in places with the underlying rocks. To these altered rocks the term muscovadite has been applied. It includes the various so-called peripheral phases of the gabbro.

On the southern and eastern border the gabbro is penetrated by and penetrates in a confused manner the red rock, with which it alternates both structurally and areally. It is believed to have resulted from the metamorphism by the gabbro of the Animikie and perhaps earlier fragmentals.

As the granites of the Archean are believed to have resulted from the softening of acidic fragmentals, so the gabbro may probably have been the result of the metamorphism or refusion of the Keewatin greenstones.

The anorthosite masses of the Beaver Bay diabase, supposed by Lawson to be of Archean age and to underlie unconformably the

Beaver Bay diabase, are believed to represent segregation phases in the main gabbro flow, and to be the same as anorthosite masses in the gabbro proper to the west.

The Beaver Bay diabase is believed to represent the upper portion of the great gabbro flow, and to be due to the first and greatest movement of the gabbro toward Lake Superior. The Logan sills belong to this part of the gabbro flow.

The Manitou division of the Keweenawan includes the surface flows, sills, and dikes which accompanied and followed the Puckwunge conglomerate. These eruptives, with the clastics associated with them, do not have a thickness in Minnesota of more than 1,000 feet. These lava sheets extend along the shore of Lake Superior from near Baptism River to near Grand Marais, except where replaced at intervals by the Beaver Bay diabase or some of the intersheeted fragmentals. They occur also in the neighborhood of Grand Portage Bay, but their extent here is not definitely known.

The most important petrological conclusions determined from the examination of the Minnesota crystalline rocks are three in number:

1. All the granites of the Archean can be explained on the assumption that they are intrusives representing the metamorphosed conditions of clastic rocks adjacent to the observed intrusions, rendered plastic by the force of dynamic metamorphism accompanied by moisture.

2. The basic Keweenawan gabbro and its derivatives are derived from the metamorphism and complete refusion of the Archean greenstones and their attendants.

3. The greensand of the Mesabi iron-bearing formation appears to have resulted from a volcanic sand, and the taconite itself from igneous forces.

Hall,[203] in 1899, describes the pre-Cambrian crystalline rocks of the Minnesota River valley of southwestern Minnesota. These rocks appear in numerous exposures along the river, protruding from the drift, from southeast of New Ulm to Ortonville on the northwest. The great bulk of the crystalline rocks are granites and gneisses. These appear for the most part in the river bottoms, but stand also in a few isolated knobs on the higher ground south and west of the river. There are many varieties of granites and gneisses, and all gradations between them. They are taken as a whole to represent the Archean or Basement Complex.

Associated with the granites and gneisses are a much smaller number of exposures of gabbros and gabbro schists. These present many varieties, all of which are believed to have resulted from the alteration of two original forms and their intergradations—a hypersthene-bearing gabbro and a hypersthene-free gabbro.

Peridotite is found in only one exposure in this valley, 3 miles southeast of Morton. The relations to the other rocks of the area could not be determined. Cutting the gneisses and gabbro schists throughout the area are numerous dikes of diabase. They vary in width from a fraction of an inch to 175 feet. Their age is probably Keweenawan.

Southeast of Redstone and near New Ulm are exposures of quartzite associated with coarse quartzite conglomerate. Near Redstone the strike of the quartzites is N. 60° to 70° W., and their dip varies from 5° to 27° N. In New Ulm the strike is N. 15° E., and the dip varies from 10° to 15° SE. The quartzite is believed to be the same as the quartzite found in a deep well at Minneopa Falls, near Mankato, Minn., which is covered by a quartzite conglomerate of Middle Cambrian age. The quartzite of Redstone and New Ulm is above the Archean granite and gneiss. It is believed to be of Huronian age, but whether Upper or Lower is unknown.

Overlying the crystalline rocks are Cretaceous shales and sandstones, which appear in rare exposures in the valley and glacial drift.

WINCHELL (ALEXANDER),[204] in 1900, prefaces a detailed petrographical description of certain phases of the gabbroid rocks of Minnesota with a brief account of the general succession in structure of formations in northeastern Minnesota. This is essentially the same as given by N. H. Winchell in Vols. IV and V of the Minnesota Survey. The correlation of this succession with the succession determined by the United States Geological Survey is discussed.

VAN HISE and CLEMENTS,[205] in 1900, together make observations on the rocks of the Minnesota coast from Duluth to Canada. The Beaver Bay diabase and the red rock of Irving's Beaver Bay group are found not to be surface lava flows, but intrusives which cut the lavas of the Keweenawan. The anorthosite of the district is almost always clearly associated with the diabase. It occurs in it in innumerable fragments, varying from those of small size to large masses, although this relation to the diabase can not be shown for some large masses of the anorthosite. The red rock intrudes both the lavas and the Beaver Bay diabase. Where the diabase is cut through by numerous dikes of the red rock, of varying size, it seems to be altered throughout. It there contains red feldspar and assumes the aspect of Irving's orthoclase gabbro; in fact, its chemical composition seems to have been effected by the minute penetration of the magma and its emanations.

WINCHELL (N. H.),[206] in 1901, publishes a geological atlas of Minnesota with synoptical description of plates. This volume contains maps and general conclusions found in Vols. IV and V of the Minnesota Survey. One additional map is published, a general geological map of the State.

Hall,[207] in 1901, describes and maps the slates and associated rocks in the vicinity of Cloquet and Carlton on St. Louis River, and certain hornblendic and micaceous schists associated with granite and diabase to the west along Mississippi and Snake rivers. He maintains that the slates and graywackes to the east and the hornblendic schists to the west belong to one and the same series, and that the schists have resulted from the metamorphism of graywacke and slate by the intrusion of granite. Still later intrusions of diabase have cut both the granites and the slates. Accepting Spurr's statement that the Carlton slates are Keewatin or Lower Huronian, the conclusion is reached that the schists to the southwest are Lower Huronian and that the intruding granites are post-Lower Huronian. If this conclusion be correct, the granites and schists of the central and eastern portions of Minnesota must be mapped as Algonkian rather than Archean, as in the past.

Hall,[208] in 1901, describes the Keweenawan rocks south and southwest from Duluth, along St. Louis and St. Croix rivers, and shows that a series of alternating lava flows and sediments lie in a synclinal northeast-southwest trough, the western border of which is marked by a profound fault. To the east of the fault the Keweenawan rocks are highly tilted to the southeast, while to the west of it the Cambrian rocks are much broken up. The relations of the fault to the distribution of the flows and analogy with other volcanic regions seem to show that the fault was a plane of weakness along which most of the lavas were originally erupted. The faulting was pre-Cambrian, Cambrian, and post-Cambrian, as shown by the fact that in some places the Cambrian rests horizontally upon the upturned Keweenawan rocks, and in others is much broken up.

Winchell (N. H.),[209] in 1902, briefly describes the iron ores of Minnesota and incidentally sketches their geological relations. No new points are added to those previously presented.

Leith,[210] in 1903, describes and maps the geology of the Mesabi district of Minnesota. The district is 2 to 10 miles in width, extending from near Grand Rapids on Mississippi River to Birch Lake, a distance of approximately 100 miles. The main topographic feature is a ridge, known as the Giants (or Mesabi) range, which extends the length of the district. The geologic formations represented in the district belong, in ascending succession, to the Archean, Lower Huronian, Upper Huronian, Keweenawan, Cretaceous, and Pleistocene. They are all separated by unconformities. The core of the Giants range is formed by Archean and Lower Huronian rocks, except for the portion in Rs. 12 and 13, where Keweenawan granite forms the core. On the south flank rest the Upper Huronian rocks, containing the iron-bearing formation, with gentle southerly dips.

The Keweenawan gabbro lies diagonally across the east end of the district.

The Archean rocks consist principally of green rocks of great variety, including dolerites, metadolerites, basalts, metabasalts, diorites, and hornblendic, micaceous, and chloritic schists. The more massive rocks frequently have an ellipsoidal structure which is characteristic of the green igneous rocks of other parts of the Lake Superior region. In addition to the green basic rocks there are present small areas of granite and porphyritic rhyolite.

The Lower Huronian series consists of sediments and granite. The sediments are graywackes, slates, and conglomerates, all metamorphosed, with bedding and schistosity practically vertical. They may be as thick as 10,000 feet, but it is thought more probable that the thickness does not exceed 5,000 feet. The Lower Huronian sediments rest unconformably upon the Archean rocks, as shown by basal conglomerates containing fragments of all the varieties of rocks found in the Archean. The Lower Huronian granite forms the main mass of the Giants range westward from a point near the east line of R. 14 W. It is intrusive into both the Archean rocks and the Lower Huronian sediments and has produced strong exomorphic effects in both.

The Upper Huronian or Animikie series consists of three formations—the Pokegama quartzite at the base, above this the Biwabik formation (iron bearing), and above this the Virginia slate.

The Pokegama quartzite comprises vitreous quartzite, micaceous quartz slate, and conglomerate. The thickness ranges from 0 to 500 feet, averaging about 200 feet. The conglomerate at the base indicates unconformable relations of the Pokegama formation to the Archean and Lower Huronian rocks.

The Biwabik formation, the iron-bearing formation, comprises ferruginous, amphibolitic, sideritic, and calcareous cherts, siliceous, ferruginous, and amphibolitic slates, paint rocks, "greenalite" rocks, sideritic and calcareous rocks, conglomerates and quartzites, and iron ores. Cherts make up the bulk of the formation. The original rock of the formation is shown to consist largely of minute granules of green ferrous silicate, thus confirming Spurr's conclusion. The material was called glauconite by Spurr, but is here determined to be a hydrous ferrous silicate entirely lacking potash, and thus not glauconite. It is named "greenalite" for convenience in discussion. The cherts and iron ores are shown to develop mainly from the alteration of the greenalite granules. The slates are in thin layers interbedded with the other phases of the iron formation. The paint rocks result from the alteration of the slates. The conglomerates and quartzites form a thin layer from a few inches to perhaps 15 feet or more in thickness at the base of the formation. They pass upward into ferruginous cherts of the iron formation rather abruptly, though usually at the contact the chert and quartzite are interleaved for a few feet. The conglomerate of the iron formation rests upon Pokegama quartzite, indicating a slight erosion interval between the Biwabik and Pokegama formations, although the interval is not shown by discordance in bedding, which is parallel in both. Heretofore the quartzite and conglomerate in the iron formation have not been discriminated from the rocks of the Pokegama formation. In the eastern portion of the range the iron formation is in contact with the Keweenawan gabbro and granite, and near this contact has suffered profound metamorphism. The characteristic rocks of this area are amphibole-magnetite cherts. The thickness of the formation may vary from 200 to 2,000 feet. The average may be 1,000 feet.

The Virginia slate is essentially a soft slate or shale formation, but it contains graywacke phases, near its base a little limestone, and near its contact with the gabbro is metamorphosed into a cordierite hornfels. The normal slate phases of the formation may be distinguished with difficulty in isolated occurrences from the slate layers in the Biwabik formation. The separation of the two is of importance to the explorer, and hence an attempt is made to determine criteria for their discrimination. The thickness of the Virginia formation can not be measured within the district, but from analogy with the Penokee-Gogebic district and the extent of the low, flat-lying area south of the Mesabi range supposed to be occupied by the slate, the formation is believed to have a very considerable thickness. The slate grades, both vertically and laterally, into the Biwabik formation.

The entire Upper Huronian series is well bedded, conformable in structure (although having a thin conglomerate between the Biwabik and Pokegama formations), and dips in southerly directions at angles varying from 5° to 20° and exceptionally at higher or lower angles. The series is gently cross folded and the axes of the cross folds pitch in southerly directions. Accompanying the folding is considerable jointing, especially in the brittle Pokegama and Biwabik formations. Indeed, in these two formations the folding is brought about mainly through relatively minute displacements along joints, while in the Virginia formation the folding has taken place mainly by the actual bending of the strata.

The thickness of the Upper Huronian series within the limits of the district mapped may average about 1,500 feet; but if the total thickness of the slate formation outside the limits of the district be taken into account, the total thickness of the Upper Huronian series is probably several times this figure.

The relations of the Upper Huronian series to the subjacent formations are those of unconformity, as evidenced by basal conglomerates, discordance in dip, difference in amount of deformation and of metamorphism, distribution of the series, and relations to intrusives.

The Keweenawan rocks consist of gabbro, diabase, and granite, all of which are intrusive into the rocks with which they come into contact. The north edge of the gabbro runs diagonally across the east end of the district from southwest to northeast, resting upon the edges of each of the members of the Upper Huronian series, and at Birch Lake against the Lower Huronian granite. North of the gabbro margin in range 12 are isolated exposures of diabase which may represent sills associated with gabbro intrusion. The granite forms the crest of the Giants range through Rs. 12 and 13. This granite has not heretofore been discriminated from the Lower Huronian granite. The exomorphic effect of the gabbro and the granite upon the Upper Huronian series has been profound.

Clements,[211] in 1903, describes the geology of the Vermilion iron-bearing district of Minnesota. Elaborate general and detailed maps accompanying this report are based on field work by Clements, Van Hise, Bayley, Merriam, and Leith.

The district ranges from 2 to 18 miles in width, and extends from a little west of Lake Vermilion, in a direction a little north of east to Gunflint Lake, on the international boundary, a distance of about 100 miles.

The rocks of the district are described under the headings, Archean, Lower Huronian, and Upper Huronian, representing series separated by marked unconformities.

The Archean of the Vermilion district is divided as follows, from the base up: The Ely greenstone, the iron-bearing Soudan formation, and the granites of Vermilion, Trout, Burntside, Basswood, and Saganaga lakes.

The Ely greenstones consist of basic and intermediate igneous rocks widely distributed in anticlinal areas, as shown by the distribution of the overlying sediments. They were originally rocks corresponding in character to intermediate andesites and basic basalts. They have been extremely altered, but retain in many cases in striking perfection the original structures, such as ellipsoidal parting and spherulitic and amygdaloidal structures. A study of their various textures and structures shows that these greenstones are unquestionably of igneous origin and largely of volcanic character. Many of them have been rendered schistose by pressure. The greenstones have also been strongly affected by the contact metamorphism due to the intrusion of great granite masses. As a result of this intrusion there have been produced from the greenstones amphibole schists, which form a marginal facies of the greenstones, lying between them and the adjacent granites. The greenstones have also been metamorphosed by the Duluth gabbro, of Keweenawan age, and granular rocks have thus been produced, which in most cases show the original textures of the greenstones, but contain also a development of fresh biotite, hypersthene, brown-green hornblende, and magnetite.

The Soudan iron formation is widely distributed in the western part of the district, but is practically wanting in the eastern half. It is found mostly in narrow belts, which consist largely of greenstone so intimately associated with the iron formation that it has been impossible to separate them on the map. The formation consists of (1) a very subordinate fragmental portion, made up of some conglomerate, clearly recognizable as having been derived from the underlying greenstones, grading up into sediments of finer character; and (2) lying above this fragmental portion, the iron-bearing formation proper, which consists of siliceous rocks, largely white cherts—though varying in color from white, green, yellow, and purplish to black—with red jasper and carbonate-bearing chert, grünerite-magnetite schist, hematite, magnetite, and small quantities of pyrite. These iron-bearing rocks are clearly of sedimentary origin. They do not now present their original characters, but are presumed to have been derived from rocks that were largely carbonate-bearing ferruginous cherts. The relation of the iron formation to the adjacent greenstones is clearly that of a sedimentary overlying an igneous series. The few basal conglomerates of the iron formation that have been found consist of pebbles derived from the underlying greenstone, showing conclusively their relationship. This relationship is obscured, however, in most places, by the absence of the conglomerates, and by the fact that the iron formation has been very closely infolded in the greenstone. In consequence of the extreme folding and of the impossibility of determining different horizons in the iron formation, it has been impracticable to ascertain its thickness.

The iron-ore deposits of the Vermilion district show a striking analogy with those of the Marquette district. Like them, they may occur in two positions with respect to the iron-bearing formation. They are found, first, at the bottom of this formation, and, second, within it, the ores in both cases being the same in character. The Ely deposits are typical of the deposits occurring at the base of the formation. They are found at the bottom of a closely compressed syncline of the iron formation, where it lies in the relatively impervious greenstone. The source of the iron was, in the first instance, the Ely greenstone. From this it was removed through the action of water and collected in the Archean sea to form the sedimentary deposits of the Soudan formation. After the folding of the formation this disseminated iron was carried by downward-percolating waters into places favorable for its accumulation, such as the bottom of this synclinal trough, where it was precipitated by oxygen-bearing waters coming more directly from the surface. Pari passu with this precipitation silica was removed, affording space for the accumulation of the iron, to form the ore deposits as now known. The Tower and Soudan deposits differ only in detail from the Ely deposit.

Granites intrusive into the Archean occupy a wide area and are named from the topographic features with which they are conspicuously associated. That these intrusives are older than the Ogishke conglomerate (Lower Huronian), which succeeds in age the Soudan formation, is shown conclusively by the fact that pebbles derived from them occur in this conglomerate. The general period of intrusion of all of these acidic igneous rocks is placed between the time of the deposition of the latest sediments of the Archean and that of the deposition of the earliest sediments of the Lower Huronian series.

The Lower Huronian occurs in two detached areas, one of which, known as the Vermilion Lake area, extends from the western limit of the area mapped, in the vicinity of Tower, to within about 11 miles of Ely on the east, and the second of which, known as the Knife Lake area, begins about 7 miles east of Ely and extends eastward to the eastern limit of the area mapped. At the base of the series there lies a great conglomerate, known as the Ogishke conglomerate, containing pebbles and finer detritus from all of the rocks of the Archean. Above this conglomerate in the eastern portion of the district there are found in a few localities small masses of the iron-bearing Agawa formation. This formation is petrographically the same as the Soudan formation. In it, however, there is in places a development of the carbonate-bearing facies. No iron ores have been found in it. Overlying the Ogishke conglomerate in the western portion of the district and the intervening iron-bearing Agawa formation where present in the eastern portion of the district, there occurs a thick series of slates of varying character, to which the name Knife Lake slates has been given. These slates have been closely folded, and have been more metamorphosed where intruded by granites of the Giants range, Snowbank Lake, and Cacaquabic Lake and by the Duluth gabbro. These igneous rocks occupy a considerable area, and their intrusive relations with the Lower Huronian are unquestionable. The Lower Huronian sediments now stand nearly vertical.

The Upper Huronian or Animikie series is found in the extreme eastern portion of the district, where it is continuous with the Animikie of the Mesabi district to the west and Thunder Bay to the east. At the bottom of the series occurs an iron-bearing formation known as the Gunflint formation. Above this is a great slate-graywacke formation to which the name Rove slate has been given. The Gunflint formation is correlated with the Biwabik formation of the Mesabi district. It has a very limited development in the Vermilion district, and its most interesting phases are especially well developed in the vicinity of Akeley Lake. In general the formation has a monoclinal dip to the south-southeast at a low angle. It has been extremely metamorphosed by the Duluth gabbro, and where most metamorphosed the rocks are composed of coarsely crystalline bands of quartz, of varying width, alternating with coarsely crystalline bands of magnetite ore, reported to vary from 1 inch up to 10 or 12 feet in thickness, and of bands of dark-green, brown, or black rocks that consist of combinations of quartz, augite, hypersthene, hornblende, olivine, and magnetite as the principal minerals, but associated occasionally with some ferruginous carbonate, actinolite, and grünerite.

The Duluth gabbro and the Logan sills, referred to the Keweenawan, occur in the eastern portion of the district. The gabbro is found to metamorphose all of the sediments already enumerated, and is thus shown to be one of the youngest rocks of the district. It is also found to be intrusive in the Keweenawan volcanics. A number of facts are enumerated to show that the gabbro and the Logan sills are of essentially the same petrographic character, although they exhibit minor differences that are readily explicable when one considers the relative amounts of the two rocks. After a consideration of these facts and of the stratigraphic relationship of the rocks the conclusion is reached that the gabbro and the sills are of essentially the same composition and age, having been derived from the same parent mass or magma. In certain localities in the Duluth gabbro are masses of titaniferous magnetite of varying but small size, with some associated minerals. These masses grade into the surrounding gabbro and were formed as the result of processes of segregation.

Cutting the Duluth gabbro are acidic dikes and dikes of basalt and diorite.

The entire district has been much folded and metamorphosed, resulting in a north-of-east and south-of-west trend of the Archean and Lower Huronian formations, marked principally by schistosity.

Winchell (N. H.),[212] in 1903, summarizes some results of the work of the late Minnesota Geological Survey. Those referring to the pre-Cambrian are as follows (the numbers are Winchell's):

5. The discrimination of two iron-bearing formations in northern Minnesota, thus separating the Mesabi range stratigraphically from the Vermilion. This observation was continued into Wisconsin and Michigan by a visit to those States, and the same duality was pointed out in the iron regions of those States and was announced for the first time in the Minnesota report for 1888. It has since been discovered that there is still a third iron horizon in northeastern Minnesota, not mentioning the titanic iron ore of the gabbro. It is the Upper Keewatin, the others being in the Lower Keewatin and the Taconic.

6. The separation of the Archean of Minnesota into two nonconformable parts, viz, the Upper and the Lower Keewatin, with a great basal conglomerate between them.

7. The determination of the oldest known rock of the Lake Superior region, a greenstone called Kawishiwin, the bottom rock of the Keewatin, the supposed earliest crust of the globe.

8. The great quartzite formation which is so prominent in the geology of Wisconsin and Minnesota is nonconformable upon the Animikie, and is a member of the brecciated beds of the Keweenawan. This has been named Sioux quartzite, Baraboo quartzite, and New Ulm quartzite. It is that which contains the red pipestone (catlinite) in southwestern Minnesota. It is the western representative of the Potsdam sandstone, of Potsdam, N. Y. This quartzite seems to be the representative of the middle Cambrian, as the Beekmantown is of the upper Cambrian.

9. The origin of the Mesabi iron ores is referred to a greensand, which has been altered, affording iron ore by concentration of the iron in certain favorable positions. Contemporary with this alteration was a concentration of silica, and this was increased by oceanic precipitation. The original greensand was found to become pebbles, and to increase into angular masses that were neither sand nor pebbles, but rather breccia. These breccia masses have at first an amorphous crystalline texture and grade into a form of the iron-bearing rock which was named taconite, and the whole was referred to volcanic action, being different forms of suddenly cooled volcanic glass and rhyolite, broken and distributed by beach action. While this volcanic débris was undergoing this transformation great quantities of silica were set free from the glass, but this silica immediately saturated the débris, producing spotted jasperoid, taconite, and sedimentary jaspilite.

This result, reached on the Mesabi range, opened the door to the understanding of the iron ores of the Vermilion range. At once the rhyolitic forms and all the igneous associations of those ores with basic igneous rocks were elucidated, thus confirming Wadsworth's idea of the igneous origin of the jaspilites of the Marquette region—rather the igneous origin of the rock which later was changed into jaspilite.

10 and 11. After prolonged field examinations the Minnesota Survey reached the conclusion that the granites of the Archean grade into gneiss, the gneiss into micaceous gneiss and mica schist, and finally into less and less metamorphic rocks that show a plain fragmental structure and sedimentary origin. There was found no exception among the Archean granites. The granites are of two dates of formation, one at the close of the Lower Keewatin and one at the close, or after the close, of the Upper Keewatin. A later granite,

associated with the gabbro, and grading into it, is of the Keweenawan, and another is still later. Hence it was inferred that the Archean granites did not spring from a deep source, but are a surface product of metamorphism carried to the extreme of fusion, on clastic materials that were later than the basal greenstones. Adventitiously they form intrusions in some of the later (and especially into the clastic) greenstones, but they are not known to penetrate the oldest greenstones. Tentatively the alkaline and the acidic siliceous elements in these early sediments were supposed to have been derived from the atmosphere, as the basal crust could not have afforded them.

In the same manner the gabbro, which becomes acidic and grades into syenite, was derived from the metamorphism and fusion of the greenstones with their clastic variations. Diabase was found to pass insensibly into gabbro, but on the other hand it is also certain that it was the original form of all the igneous greenstones, and that it must have had a deep-seated source, and has still a deep-seated source.

These belts of intensest metamorphism, whether productive of granite or of gabbro, have a parallelism with one another and with the northwestern rim of the great synclinorium of the basin of Lake Superior, marking successive continental folds, in harmony with a system which continued through Archean and Taconic time, and even into the upper Cambrian.

Van Hise, Bell, Adams, Miller, Lane, Merriam, Sebenius, and Leith,[88] in 1904, visited the Mesabi district of Minnesota and made observations confirming the conclusions reached by Leith in previous years. Two unconformable Huronian series, intruded by granites, were observed to be separated by unconformities and to rest on a Basement Complex consisting of a basic Keewatin division and an acidic Laurentian granite division intrusive into the Keewatin.

In the Vermilion district observations were made confirming the conclusions previously reached by the geologists of the United States Geological Survey. One sedimentary series, Lower Huronian, was observed to rest upon a Basement Complex consisting of a basic Keewatin division and an acidic Laurentian division.

Leith,[213] in 1907, describes the geology of the Cuyuna iron range of Minnesota. This range is the most recently discovered range in the Lake Superior region. It lies along the line of the Northern Pacific Railway, near Mississippi River, in the vicinity of the towns of Brainerd, Deerwood, and Aitkin, in Crow Wing, Aitkin, and Morrison counties, in north-central Minnesota. Its boundaries are still being extended and few would care to draw limits in any direction. The area of present greatest activity lies to the south and east of Mississippi River, in Tps. 43, 44, 45, 46, 47, and 48 N., Rs. 28, 29, 30, 31, and 32 W.

From the information so far available, consisting largely of drill samples, the succession of rocks for the Cuyuna district, from the base upward, is as follows:

Quartzite and its altered equivalents, quartzose, micaceous, and hornblende schists.

Iron formation, consisting principally of iron carbonate where unaltered, but largely altered to amphibole-magnetite rock, ferruginous slates, and iron ore. The ores thus far found are soft, reddish, slightly hydrated hematite, reddish slaty hematite, and hard, blue, banded, siliceous magnetite and hematite.

Chloritic and carbonaceous slate, interbedded in its lower part with iron formation.

Intrusive granite and diorite, principally the latter.

Cretaceous sediments.

Glacial drift, 80 to 350 feet.

It is possible that some of the igneous rock is really older than the sedimentary series and lies unconformably beneath it, but no evidence of this has yet been found, and the structural relations do not favor this view. All the sediments are conformable with the exception of the Cretaceous and the drift.

The sediments are bent in upright symmetrical folds and the slaty members are cut by schistosity dipping steeply away from the axial planes of the folds. For the most part erosion has not gotten down through the slate. Ore is found only where erosion has cut through the slate to the iron formation. The magnetic belts are carried by the lower members of the iron formation and therefore mark the foot walls near the axes of the folds.

The pre-Cretaceous rocks are pre-Cambrian and the sediments are correlated with the Upper Huronian series.

Zapffe,[214] in 1907, gives a full account of the geology of the Cuyuna iron district of Minnesota as known to date, with details as to exploration. The general succession and structure are essentially those described by Leith. Much of the fieldwork was done in common by the two men.

Abbott,[215] in 1907, describes the Ely iron-bearing trough of the Vermilion district of Minnesota and shows in detail the relations of the iron formation to the associated green schists of the Keewatin and the sediments of the Lower Huronian. It is concluded that while the iron formation is in general above the greenstone and infolded with it, it is in part interbedded with the greenstone flows of the Keewatin.

Sardeson,[215a] in 1908, discusses the geological history of the Redstone quartzite and its associated rocks between New Ulm and Courtland in the valley of Minnesota River, and principally the post-Cambrian history as shown by relations with later rocks.

For fuller summaries of articles referring to the Minnesota ore-bearing districts see Monographs XLIII and XLV of the United States Geological Survey.

SECTION 4. PART OF ONTARIO NORTHWEST, NORTH, AND NORTHEAST OF LAKE SUPERIOR.

SUMMARY OF LITERATURE.

Bigsby,[216] in 1825, describes in detail the rocks at many points along the north shore of Lake Superior, between the Falls of St. Mary and Grand Portage, an interval of 445 miles. The varieties of rocks are few in number when compared with a similar extent of country in Europe. Of mica slate, clay slate, etc., not a vestige was found, not even in débris, nor of any secondary deposits above the Mountain limestone. Sandstone, under various modifications, occupies the greatest space, in intimate connection with the next prevailing rocks, the amygdaloids, porphyries, and greenstone trap. The alternating granites and greenstones of the northeastern and eastern coasts are nearly equal in quantity to these. The granites and syenites are not stratified. The porphyry, amygdaloid, and sandstone are considered contemporaneous and newer than the granites, although not much, as indicated by the transitions and alternations occurring about Gargantua. The age and connections of the greenstone trap the author is not prepared to state. The sandstone is most probably Old Red, a conclusion reached from the materials composing it, and its direct superposition on inclined rocks in this and other great lakes of the St. Lawrence, and because it supports a fossiliferous limestone full of Productæ, Turbinoliæ, Caryophylliæ, trilobites, Conulariæ, encrinites, and orthoceratites, etc. The granite and syenite seem to be of the same age and belong to the Transition or to the youngest of the Primitive.

On the old route from Lake Superior to the Lake of the Woods (for 430 miles) is an alternation of chloritic greenstone and amphibolitic granite, but at and toward the Lake of the Woods the greenstone passes into gneiss and mica slate, traversed in many ways and in great quantities by graphic granite.

Bayfield,[217] in 1829, gives an outline of the geology of Lake Superior. The rocks of the lake are divided into four divisions: First, the inferior order, comprising granites, which almost always contain more or less hornblende. In this division neither gneiss nor mica slate was met with, although the granite by the abundance of its mica or lamellar structure may for a short distance assume the appearance of either. Second, the submedial order, which includes greenstones, common jaspery variety of greenstone slates, flinty chlorite, talcose slate, and in one place alone Transition limestone, with perhaps traces of graywacke. Third, trap or overlying rock, the most of which is amygdaloid; various kinds of porphyry are next in quantity; then trap, greenstone, syenites, and pitchstone.

Fourth, the medial order, the only rock of which is the Old Red sandstone. Then follows an account of the distribution of each of these orders. The amygdaloid with little doubt rests upon the syenite and granite, although the junction was never seen. The amygdaloid passes into greenstone on the one hand, simply by being divested of its nodules, and into porphyry on the other. The Old Red sandstone may be traced from one extremity of the lake to the other. Its existence is noticed on both shores, and it is traced across the lake by many of the islands, so as to leave no doubt of its being a general formation throughout the whole of the basin of Lake Superior. It is generally horizontally stratified or nearly so. There are many instances of the conjunction of the sandstone and granite, which serve to prove that the sandstone was deposited after the granite occupied its present position. The sandstone, when conglomeratic, as is very frequently the case, contains fragments of the trap as well as of the inferior order, which are rounded by attrition, and it is therefore plain that the sandstone is later than the trap rocks. Organic remains were sought in this rock, but never discovered. It is placed as the Old Red because of its position immediately on the granite, its structure, and component parts.

Bayfield,[218] in 1845, places with the Primary rocks most of the clastics on the north shore of Lake Superior. These are cut by various greenstones. A red sandstone forms nearly the entire southern boundary of the lake. In places it is shattered by the upheaval of granite and by trap rocks which enter into the composition of its conglomerates. At Nipigon Bay it is overlain by an immense bed of greenstone. It is probable, although not certain, that this sandstone underlies the fossiliferous red sandstone of St. Marys.

Logan,[219] in 1847, in a report on the geology and economic minerals of Lake Superior, gives an account of a rather detailed examination of the north shore of Lake Superior from Pigeon River to Sault Ste. Marie. Michipicoten Island was also examined. Lake Superior appears to be set in a geological depression, which presents formations of a similar character on both the north and the south sides, dipping to the center. The series on the north, in ascending order, consists of the following: (1) Granite and syenite; (2) gneiss; (3) chloritic and partially talcose and conglomerate slates; (4) bluish slates or shales, interstratified with trap; (5) sandstones, limestones, indurated marls, and conglomerates, interstratified with trap. The gneiss is succeeded by dark-green slates, which at the base appear to be occasionally interstratified with beds of the subjacent granite and gneiss. Some of these slaty beds have the quality of a greenstone, others are a mica slate, and a few are quartz rocks. Higher in the series are conglomerates, the pebbles of which are all apparently from hypogene rocks. Formations 4 and 5 rest unconformably upon 1, 2, and 3, having sometimes basal conglomerates, the pebbles being of quartz, red jasper, and slate. The upper part of 3 strongly resembles the upper slates at Lake Temiscaming. The succession of conglomerate and pebbly slates at Gros Cap has a total thickness of 1,700 feet. In group 5 are the succession of rocks at Michipicoten Island, a portion of those at Thunder Bay, and at other localities. At Michipicoten the thickness of the interbedded volcanics and water-deposited clastics is not less than 10,000 or 12,000 feet. Group 5 exhibits an unconformity to the granite. The conclusion that the Copper-bearing series is older than the Potsdam sandstone, arrived at by Houghton in 1841, is thought to be probably true.

Murray,[220] in 1847, in an account of Kaministiquia and Michipicoten rivers, divides the geological formation into three groups: (1) Granite, syenite, gneiss, micaceous and chloritic schist; (2) blackish argillaceous slates, with associated trap; (3) drift clays and sands. At the portage of the Kaministiquia a massive syenite passes into a gneissoid syenite, upon which rest conformably dark-colored altered slates, one rock passing imperceptibly into the other. The junction of 1 and 2 was not observed.

Logan,[221] in 1852, finds the rocks of the north shore of Lake Superior to have the following succession: Granite, syenite, and gneiss, or micaceous and hornblende gneiss, which are succeeded by chloritic and talcose slates, interstratified with obscure conglomerates with a slaty base. Upon these rest unconformably bluish slates, with belts of chert and limestone toward the bottom, and thick flows of greenstone trap at the top. Above these are alternations of sandstones, conglomerates, amygdaloids, and traps, the whole thickness of the upper series above the unconformity being not less than 12,000 feet. The conclusion is reached that this upper series is the equivalent of the Potsdam sandstone, which rests unconformably upon the tilted beds of the Lake Huron series, and that both are contemporaneous with the Cambrian series of the British Isles.

Bigsby,[222] in 1852, finds the crystalline strata of the Lake of the Woods to conform in strike with those several hundred miles southward on the river Mississippi. Granite occupies the axis in the northeastern part of the Lake of the Woods, and is always the lowest rock, the gneiss, mica schist, and greenstone dipping away from it on both sides. Greenstone is perhaps the most abundant rock in this part of the lake, and greenstone conglomerates are found which contain black masses of greenstone lying with their greater length parallel to the strike. The granites and mica slates are intimately associated, and the granite includes greenstone in a thousand tortuous masses, tongues, and slender veins. Also the granite is cut by greenstone.

BIGSBY,[223] in 1852, divides the rocks about Lake Superior into (1) metamorphic, including greenstone, slates, schists, gneisses, quartzites, jaspers, and crystalline limestones; (2) aqueous, including the calciferous and Cambrian sandstones and conglomerates; (3) igneous, including granite, syenite, and trap. The lake is a trough or basin of Cambrian or Silurian sandstone, surrounded by two irregular and imperfect zones, the inner consisting of traps with conglomerates, the outer, of metamorphic, flanked by igneous rocks. The metamorphic rocks, with the exception of quartzite and jasper, the oldest in the lake, support unconformably the sandstone. These rocks have been upheaved and altered by the intrusion of igneous rocks. The sandstone is generally horizontal, except near the intrusive rocks, where it rises at high angles and passes into jasper, porphyry, gneiss, or quartzite. The conglomerate is of the same age as much of the sandstone, and is between it and the trap; and there is reason to believe that the sandstone is interleaved with trap. The igneous rock, granite, everywhere forms the nucleus of the anticlinal axes. The trap rocks are divided into crystalline mountain masses—sometimes anticlinal and syenitic, into bedded traps, and into dikes intersecting igneous and metamorphic rocks; but all are portions of one long series of volcanic operations.

BIGSBY,[224] in 1854, finds the geology of Rainy Lake to be as follows: Chloritic and greenstone slates, gneiss, and mica slate, in proportional quantities in the order here set down, seem once to have occupied the lake basin, with an east-northeast strike, and a north-northwest dip, at a high angle usually. But subsequently a very extensive outburst of granite, with some syenite, has taken place, to the great disturbance of the stratified rocks, and penetrating them both in intercalations and crosswise. These intrusive rocks occupy a very large portion of the lake, most of the western shore, nearly all of the eastern trough or arm, and much of the east end of the lake about Stokes and Hale bays. Intercalations of syenite and hornblende greenstone are numerous, and so are veins of porphyritic granite traversing the gneiss in all directions. The chlorite slate, greenstone, gneiss, and mica slate are conformable with one another.

DAWSON (Sir WILLIAM),[225] in 1857, finds between Sault Ste. Marie and Mamainse three of the oldest formations in America or the world. Beginning at the top are: (1) Potsdam sandstone; (2) an enormously thick formation of conglomerates, sandstones, slate, and trap, constituting the Huronian series of Logan; (3) a still older Laurentian series, represented here principally by syenitic rocks which have afforded the material of the Huronian conglomerates. The sandstones and conglomerates of the second series probably unconformably underlie the Potsdam sandstone, as is indicated by their high inclination and disturbed condition.

Logan,[226] in 1863, finds on the north shore of Lake Superior crystalline stratified rocks which occur in extensive tracts about Rainy Lake and Lac la Croix, as well as adjacent to Lake Superior, which are probably of Laurentian age. There are three areas of Huronian along the northeast coast of Lake Superior, and a narrow strip of Huronian rocks is seen along Thunder Bay.

The Laurentian gneiss is succeeded by green or gray slates, which at the base appear to be interstratified with feldspathic beds of the reddish color belonging to the subjacent gneiss. Higher in the series the dark-green slates become interstratified with layers holding a sufficient number of pebbles of different kinds to constitute conglomerates. Often the pebbles, unless they are of white quartz, are very obscurely distinguishable on fractured surfaces, both the pebbles and the matrix having a gray color and showing very little apparent difference in mineral character.

The Doré section, composed of strata inclined only 10° or 15° from the vertical, 1,700 feet thick, consists mainly of green slate rock and a green slate conglomerate the pebbles of which are of granite, gneiss, syenite, etc., and some of the bowlders of which are a foot in diameter. At the Doré the lower part of the section assumes more the character of a gneiss and becomes interstratified with feldspathic layers. The Laurentian appears to be conformable with and to grade into the Huronian on Kaministiquia River.

The Huronian formation of Lake Superior is unconformably overlain by a second series of copper-bearing rocks, which may conveniently be divided into two groups, the lower consisting of bluish slates or shales, interstratified with chert beds, sandstones, and trap, and the upper consisting of a succession of sandstones, limestones, marls, and conglomerates, also interstratified with trap, which is often amygdaloidal. At the top of the lower group is a crowning overflow of trap 200 or 300 feet thick, and the whole of it has a thickness of 1,500 or 2,000 feet. The upper group contains a great quantity of trap layers and has an enormous trappean overflow, the total volume having a thickness of between 6,000 and 10,000 feet. Dike rocks, consisting of greenstone, porphyry, and syenite, are found to be of two ages. The lower group composes the whole country, both islands and mainland, between Pigeon River and Fort William. The upper group occupies the coast and islands from the south side of Thunder Cape to the east end of Battle Islands, east of Nipigon Bay. It also covers a large part of Isle Royal and Michipicoten, at which latter island the total volume of the formation is at the most moderate estimation 12,000 feet. On the east coast of Lake Superior this group is found at Cape Choyye, Cape Gargantua, Point aux Mines, Mamainse, where the breadth across the measures is sufficient to give a thickness not far from 10,000 feet, and at three other places on the coast between the last point and Sault Ste. Marie.

As to the age of this series, the fact that the generally moderate dips of the red sandstone at Sault Ste. Marie contrast with the higher inclinations of the copper-bearing rocks, while none of the many dikes are known to intersect the Sault Ste. Marie sandstone, leads to the suspicion that the latter may overlie unconformably the rocks which, associated with the trap, constitute the copper-bearing series. The affinities of the Sault Ste. Marie red sandstone appear to bring it into the position of the Chazy rather than the Potsdam formation, and if this were established the copper-bearing portion of the Lake Superior rocks might reasonably be considered to belong to the Calciferous and the Potsdam formations.

MACFARLANE,[227] in 1866, gives observations on the Laurentian, Huronian, and Upper Copper-bearing rocks of Lake Superior. Here the Laurentian series seems to differ somewhat from the same series in other parts of Canada. The rocks are all highly crystalline, seldom thoroughly gneissoid, and all are unaccompanied by crystalline limestone, which is such a marked feature in some Laurentian districts. The gneiss strata are much contorted and are intersected with granite in almost equal quantity with the gneiss itself; and although the granite occurs in irregular veins, at the point of junction it is as firmly cemented with the gneiss as any two pieces of one and the same rock could well be. On the Goulais Bay fragments of hornblende rock or schist up to 3 feet in diameter are inclosed in a coarse-grained syenitic granite.' In this series the oldest rock is the most basic in constitution, and this is the case without regard to mineralogical composition or structure of the rocks associated together. The indistinctness of parallelism in the rocks renders it a matter of extreme difficulty to form any clear ideas as to their succession, even if such should exist. Besides the above rocks there are considerable areas of granite, syenite, dolerite, diorite, and melaphyre found in the Laurentian.

The rocks of the Huronian system consist in large part of diabase, amygdaloid, diabase schist, greenstone, breccias, and slaty greenstones. Interstratified with these are slate, slate conglomerate, and quartzite. The bowlders and pebbles of the conglomerate of Dore River are for the most part granite; they are elongated and flattened, the pebbles sometimes being scarcely distinguishable from the slate. Granitic veins or masses, like the Laurentian, are found in the schistose greenstones, which are regarded as belonging to the Huronian. As to the succession of the strata, the author is as much at a loss among the irregular schistose Huronian greenstones as among the gneissoid granites of the Laurentian.

The Mamainse section of Upper Copper-bearing rocks consists of interbedded basic lava flows, often amygdaloidal, sandstones, and conglomerates, the total thickness being more than 16,000 feet. The total thickness of the series at Mamainse and Michipicoten is believed to be at least 20,000 feet. As to the relations of the horizontal Sault sandstone to the Upper Copper-bearing series, a place was found on the south of Point aux Mines where the Mamainse series adjoins the Laurentian rocks. The lowest member of the former is unconformably overlain by thin-bedded bluish and yellowish gray sandstone, striking N. 50° E., and dipping 18° NW. The lowest layer is a conglomerate with granitic and trappean bowlders, and is followed by thin-bedded sandstones, and these by thin shaly layers.

MACFARLANE,[228] in 1868, describes the rocks of the north and east shores of Lake Superior. He here finds four formations—the Laurentian, Huronian, Upper Copper-bearing rocks, and St. Mary sandstone. The most prevalent rocks of the Laurentian series are of a massive crystalline character, more of a granitic than of a gneissic nature. Almost equally frequent with the granitic and gneissic rocks are aggregates of rocks which can be described as brecciated and intrusive, gneissic, granitic, and syenitic rocks. In these the order of age is always from basic to acidic. In one case fragments of hornblende schists are found inclosed in syenitic granite, which is cut by granite dikes of different ages. It is believed that these rocks are wholly of igneous origin, representing a single period of time—the basic rock first solidified; they were then rent off, broken up, and the crevices filled with more siliceous material, which gradually solidified, after which occurred another general movement with further intrusion of the most siliceous materials.

In the Huronian series is placed diabase, augite porphyry, calcareous diabase, diabase schist, greenstone and greenstone slate, chlorite schist, quartzite, hematite, greenstone breccia, and slate conglomerate. The slate conglomerate frequently contains granite pebbles which are in roundish, lenticular, bent, long-drawn-out masses, with a diabase schist or greenstone slate matrix. These rocks locally have a sedimentary appearance, but are believed to be due to the subsequent intrusion of the Huronian rocks, which have caught granite fragments in them and, by movement and heat, have softened and much distorted the contained fragments. It follows that far the greater number of the Huronian rocks are regarded as purely igneous.

In the Upper Copper-bearing series are distinguished melaphyre of various kinds—melaphyre breccia, porphyrite, porphyritic conglomerate, felsite tuff, polygenous conglomerate, and sandstone. The polygenous conglomerate contains, at Mamainse, fragments chiefly of granite, gneiss, quartzite, greenstone, and slate, while some of the newer contain abundant bowlders of melaphyre and amygdaloid. The igneous rocks and sandstones are regularly interstratified with each other. In many places the trap lies unconformably upon the upturned and contorted edges of the sandstone.

Along the coast and upon many islands is found an almost horizontal red sandstone, which is supposed to be a continuation of the Sault Ste. Marie sandstone. Its relations to the Copper-bearing rocks are not clearly made out, but the lowest members of the Mamainse series are unconformably overlain by sandstones which may be the equivalent of the horizontal red sandstones, but their lithological character is different. It is suggested, on lithological grounds, that this red sandstone may be of Permian age.

MACFARLANE,[229] in 1869, describes at Thunder Cape a series of interstratified argillaceous and white and red dolomitic sandstones, which had been disturbed and eroded before the flow appeared which forms the summit rock of the cape.

BELL,[230] in 1870, gives an account of the geology of the northwest coast of Lake Superior and the Nipigon district. The Copper-bearing rocks are divided into a lower group and an upper group, and each of these groups is separated into several divisions. In the upper group only is found interbedded trap. Different portions of this series are found overlying unconformably in certain places the Laurentian and in others the Huronian; and the great trap overflow which crowns Thunder Cape rests in various places unconformably upon different members of both the upper and the lower groups of the Upper Copper-bearing series. On account of the great thickness of this series, the absence of fossils, the prevalence of marls and sandstones charged with red oxide of iron, and of basalts, amygdaloids, and trap rocks, and various zeolites and native copper, this series is considered as probably of Permian or Triassic age. Between the margin of the Upper Copper-bearing rocks on Thunder Bay and the Laurentian range all the country not occupied by the syenitic areas appears to be composed of rocks of the Huronian series, consisting of diorites, dioritic conglomerates, hornblendic and fine-grained micaceous slates, with some quartzites.

BELL,[231] in 1872, finds in the country north of Lake Superior, between Nipigon and Michipicoten rivers, both Laurentian and Huronian rocks. The former includes gneisses and granites, and the latter includes slates, conglomerates, massive and schistose diorites, fine-grained gneisses, mica schists, micaceous, hornblendic, chloritic, feldspathic, and epidotic schists, slates, granites, and iron ore. The Huronian rocks dip in various directions. At White River hornblendic schist and light-gray gneiss are interstratified with massive granitic gneiss, and similar schists appear to rest conformably upon massive gneisses for a long way north of the river.

BELL,[232] in 1872, finds in the country between Lake Superior and Albany River areas of Laurentian and Huronian rocks. Between

Mousewake Lake and Martins Falls bands of gneiss are interstratified with the schists, and just at Martins Falls the latter have become entirely replaced by red and gray gneisses, apparently showing a conformable passage from the Huronian into the Laurentian rocks. A similar blending of these formations was noticed last year in the neighborhood of White Lake.

SELWYN,[233] in 1873, finds between Mille Lacs and Separation Lake and the Lake of the Woods a series of parallel bands of schistose and slaty layers where hitherto was supposed to be almost exclusively the Laurentian gneiss. The facts observed lead to the conclusion, as stated by Bell, that the two series are in conformable sequence; yet it is far from improbable that this apparent conformity is only local and that a more extended and detailed investigation of the structure would show that there is in reality a very considerable break between the Laurentian gneiss and the overlying schistose and slaty strata referred to the Huronian rocks. The evidence as to the age of these latter is not satisfactory. They resemble as closely the altered rocks of the Quebec group as they do the Huronian of Lakes Huron and Superior.

BELL,[234] in 1873, finds in the country between Lake Superior and Lake Winnipeg rocks belonging to the Laurentian, Huronian, and Upper Copper-bearing series. The southern shores of Mille Lacs are composed of Huronian strata. The Laurentian gneiss and Huronian schists at many places alternate with each other. The junction of the Laurentian rocks on the north with the Huronian schists on the south occurs at Rat Portage on the Lake of the Woods. The two rocks are seen almost in contact with each other and have the same strike and dip. The rocks classified as Huronian consist principally of a great variety of crystalline schists in which a greenish color prevails. In addition to these are grayish quartzites and schists, sometimes with iron ore, diorites, and imperfect gneisses. The areas of granite and syenite in the region, which vary from patches to areas many miles in length, are always more or less intimately connected with the Huronian bands. The distinction between the Laurentian and Huronian rocks is chiefly of a lithological character, the Huronian appearing to succeed the Laurentian conformably. The Upper Copper-bearing series, composed of slates, marls, sandstones, and traps, lie nearly horizontally on the edges of the Laurentian and Huronian rocks.

HUNT,[235] in 1873, applies the name Animikie group to the lower division of Logan's Upper Copper-bearing series of Lake Superior as it occurs at Thunder Bay, where it includes dark-colored argillites and sandstones overlain with a slight discordance by red and white sandstones, apparently the same as those of the Keweenaw district. The dark-colored sediments of the Animikie group rest directly upon the edges of the crystalline Huronian schists and are cut by great dikes of diorite. The great Keweenaw group, with its cupriferous amygdaloids, is here absent, although met a few miles to the east. This group, as shown by Brooks and Pumpelly, occupies a place between the Huronian schists and the nearly horizontal red and white sandstone of the region, which is itself below the Trenton limestone.

Bell,[236] in 1874, in the country between the Red River and the South Saskatchewan, finds extensive mica schists and gneisses; but a broad band of schist, having the character of the Huronian formation, crosses the central part of Rainy Lake. On the islands of the Lake of the Woods the granites, gneisses, and Huronian schists are intricately mingled with one another.

Dawson (G. M.),[237] in 1875, gives an account of the geology of the Lake of the Woods, where the rocks are wholly Laurentian and Huronian. The Laurentian formation is represented by a great thickness of granitoid and thick-bedded gneisses, which pass upward into thin-bedded gneisses and highly crystalline micaceous and hornblendic schists.

The Huronian rocks are more variable in character. The lowest beds are, for the most part, hard green rocks, with little traces of stratification, but hold some well-stratified micaceous and chloritic schists and also imperfect gneiss. On these rests a great thickness of massive beds characterized by the predominance of conglomerate, but including quartzites and dioritic rocks. Above these is an extensive series of schistose and slaty beds, generally more or less nacreous and chloritic or talcose, but often hornblendic and micaceous. They inclose also conglomerates, quartzites, and diorite beds. It is believed that two movements have conspired to form the present features of the region, both being post-Huronian. The first of these is connected with the post-Huronian granite eruptions; the second and more important is believed to have taken place later, and to it is supposed to be due the parallelism in the folding of the Laurentian and Huronian rocks. At Rat Portage the junction of the Laurentian and Huronian is so sharply defined that the hand can be laid upon it. This sharp contact is believed to be due to faulting. Adjacent to the granite the Huronian slate series is metamorphosed, and the occasional gneissic aspect of the Huronian is attributed to the granitic intrusions. The large Y-shaped granite mass in the northwest angle, in contact with the altered sedimentary rocks, assumes a more basic character and a darker aspect, becoming blackish gneissic diorite and gray syenitic diorite. The conglomerate beds are of immense thickness and could perhaps be best described as slate conglomerates. The pebbles generally resemble the matrix, and best appear upon a weathered surface; for on a freshly broken surface no clear distinction appears between the fragments and the inclosing materials, and the rock differs from the more compact altered schists and slates only in its rougher surface of fracture and a somewhat spotted character. The greenstone conglomerates of Bigsby resemble roughly fractured pieces of diorite in a dioritic paste. The quartzites show a tendency to run into conglomerates, and certain of the conglomerates have the aspect of a volcanic breccia. There is an entire absence of any granitic or gneissic beds in the conglomerates and breccias, and in this respect these Huronian rocks differ from the typical area. It is suggested that this fact may mean that the formation of the whole Huronian series took place subsequent to that of the typical Huronian, and therefore are perhaps more nearly equivalent to those of the Quebec group. The granitoid gneisses and intrusive granites are universally cut by veins of red orthoclase feldspar associated with quartz; and basic diorite dikes cut both the granitic and the altered Laurentian rocks.

BELL,[238] in 1875, describ[illegible] shore of Lake Superior the Laurentian, Huronian, and Upper Copper-bearing rocks. The Huronian occupies a large extent of country, alternating with bands of Laurentian, on both the north and the south shores of the lake. North of Lake Superior the Laurentian rocks consist for the most part of gray and reddish gneiss, with micaceous belts and mica schists. In the same region the Huronian rocks are mostly of a schistose character, the most common of which are greenish schists and imperfect gneisses, which include micaceous, hornblendic, dioritic, porphyritic, siliceous, cherty, chloritic, felsitic, and argillaceous schists, more rarely dolomitic schists, and occasionally bands of magnetic iron ore and hematite. Connected with the Huronian rocks are various patches of granite and syenite which show no stratification. In the Nipigon basin the Upper Copper-bearing rocks have their maximum development in Canadian territory. The basin consists of marls and sandstones, often covered with trappean outflows. For this Upper Copper-bearing series the term Nipigon group is proposed.

BELL,[239] in 1876, finds on Lake Winnipeg extensive areas of Laurentian gneiss and Huronian schist. The run of the stratification is pretty uniform, averaging from 50° to 60° south of east, being almost at right angles to the general strike of the Laurentian and Huronian rocks in the great region north and northwest of Lake Superior.

BELL,[240] in 1877, describes the rocks from the head of Moose River to Michipicoten and Lake Superior; also along the Goulais River. Before reaching Lake Superior there are several broad alternating belts of Laurentian gneiss and Huronian schist. The Huronian hornblende and mica schists are cut by granite veins of various sizes, one of them 100 feet thick. On Goulais River there are again alternations of Laurentian and Huronian rocks.

BELL,[241] in 1878, gives observations on the geology of the east shore of Lake Superior from Batchawana Bay to Michipicoten River. The Upper Copper-bearing series of Mamainse is calculated to have a thickness of 22,400 feet. It consists of a great variety of amygdaloids, volcanic tuffs, felsites, cherts, crystalline diorites, sandstones, and coarse conglomerates, the latter forming one of the most striking features in the series as it passes into a bowlder conglomerate. The bowlders are sometimes crowded in a sandy matrix, the largest running as high as 3 feet 8 inches in diameter, but the majority are under 1 foot. Far the greater number consist of granite and crystalline schists like those of the Huronian series, but there are also found white quartz, amygdaloid, and gneiss. Granites, gneisses, and schists, as well as basaltic dikes, are found at many points. Cape Choyye is composed of Huronian rocks, which consist of mica schists and hornblende schists, slaty quartzite, and massive diorite. The rocks of Gros Cap are mostly slaty diorite, interstratified with siliceous rock, in which occur exposures of purplish red hematite. A dioritic slate west of Gros Cap holds layers and lenticular patches of felsite and also rounded pebbles of granite, the largest of which are 9 inches in diameter.

MACFARLANE,[242] in 1879, in discussing Selwyn's paper on the Quebec group, maintains that there are frequently found between the water and the Laurentian or Huronian hills narrow strips or patches of rocks of the Upper Copper-bearing group. Such localities are Gros Gap, south shore of Batchawana Bay, and Cape Gargantua. The conglomerates are full of Huronian débris, and in Batchawana Bay may be observed bowlders of red jasper conglomerate, the characteristic rock of the typical Huronian. On Michipicoten Island the igneous and sedimentary strata of the Upper Copper-bearing rocks have a dip of 25° SE., while the nearest Huronian rocks dip 34° to 55° N.

BELL,[243] in 1883, gives a further account of the distribution of the rocks of the Lake of the Woods and adjacent country. They are not different from those mentioned in his previous report for 1872–73. The line between the Laurentian and Huronian systems crosses Winnipeg River at Rat Portage, keeps near the railway to a point between Lake Lulu and Keewatin Mills, where it crosses it diagonally and continues in a westerly direction on the south side of the track.

SELWYN,[244] in 1883, as a result of an examination of the north shore of Lake Superior from Thunder Bay to Sault Ste. Marie, and thence eastward to Echo Lake, fails to find evidence of the supposed unconformity of the Huronian and Laurentian. The author can give no better reason for supposing that certain sets of beds belong to the so-called Laurentian and others to the Huronian system than a considerable difference in the lithological characters.

The Laurentian are essentially granitoid, gneissic, and feldspathic, while the Huronian are quartzose, hornblendic, schistose, and slaty. As a whole the latter have a somewhat altered aspect and contain pebbles of rocks—granite, gneiss, quartzite, etc.—similar to those which form the Laurentian strata beneath them, while others, however, are not recognizable as from any known Laurentian sources. Bands of limestone and dolomite, more or less crystalline, are found in both Laurentian and Huronian areas, and, if we except the disputed form Eozoon, no fossil whatever. The Huronian follows and does not rest unconformably upon the Laurentian. The Nipigon or Keweenian is later in age than the Animikie. No definite opinion can be expressed as to the position of the crowning overflow of Thunder Cape.

SELWYN,[245] in 1883, describes the trap and sandstone of Lake Superior as unconformably upon and entirely distinct from the Huronian. The series is divisible on the Canadian shore into two, and perhaps three, divisions, between which there may be slight unconformities, which are, however, no greater than might be occasioned by the intermingling of sedimentary strata with volcanic material. The groups are, in ascending order: (1) The shales, cherts, dolomites, and sandstones, interbedded with massive diabase or dolerite, of Pie Island, McKays Mountain, and Thunder Cape. (2) Conglomerates, shales, sandstones, and dolomites, interstratified with massive beds of volcanic material, amygdaloids, melaphyres, tuffs, etc., many thousands of feet thick, occupying the east shore of Black Bay, Nipigon Strait, St. Ignace, Michipicoten Island, Gargantua, Mamainse, etc. (3) The Sault Ste. Marie sandstone, which may be only the upper part of 2 without any intermingling of volcanic material. The whole together is lower Cambrian, there being no evidence whatever of their holding any other place in the geological series. The first of these groups is the Animikie series, while the second is the Keweenian.

SELWYN,[246] in 1885, places the crowning overflow of McKays Mountain, Thunder Cape, and Pie Island, etc., as a part of the Animikie. There was found no evidence of unconformity from the base of the Animikie to the top of the Keweenian as developed on Thunder Cape and in the surrounding region.

LAWSON,[247] in 1886, gives a report on the geology of the Lake of the Woods region, with special reference to the Keewatin (Huronian?) belt of the Archean rocks.

Comprising a large part of the Lake of the Woods is a series of crystalline and semicrystalline schists to which the term Keewatin is applied. The term Huronian is not used, because it is very doubtful if the series belongs to this period. The rocks are found to differ fundamentally in lithological character from Logan's Original Huronian.

In the Keewatin, quartzites are unimportant; there are no true basal conglomerates; and the fragmentals of the Lake of the Woods are of volcanic origin. No bedded limestones were observed. Structurally, also, the two series are fundamentally different. The Lake of the Woods schists are folded with the associated granite gneisses, which are referred to the Laurentian, while the Huronian series has not partaken of the folding to which the adjacent gneisses have been subject. Further, the large areas of granite are found to be intrusive in both the Laurentian gneiss and the Keewatin schists, while in the Huronian of Logan such intrusions, if present at all, are mentioned at only one locality. The slate conglomerate of Dore River appears to resemble the Lake of the Woods agglomerates, but this area is distant from the typical Huronian region and the rocks appear to differ from those of the Huronian lithologically, as well as being in a nearly vertical attitude. These differences between the Dore and Huron areas, with their geographical separation, may warrant the belief that possibly Logan embraced under one designation two distinct series. As to Irving's position that the Animikie series is probably the equivalent of the Huronian, it is considered exceedingly probable that the flat-lying unfolded Animikie is much later than the Lake of the Woods schists.

The rocks of the region, including both the Laurentian and the Keewatin, comprise gneiss, granite, felsite, schistose hornblende rocks, diabase, diorite, serpentine, coarse clastic rocks and agglomerates, mica schists, slates, quartzites, clay slates, felsitic schists, hydromica and chlorite schists, carbonaceous schists, and limestones. The massive granites sometimes grade into foliated gneisses. Dikes of granite have sometimes foliated structures parallel to their sides. The agglomerates are not ordinary clastics, but are of volcanic origin. Both paste and included fragments have evidently had a common origin and been laid down together, perhaps not even always under water. The fragments are usually more or less elongated or lens shaped, due to pressure. The greatest planes in the fragments are parallel with the planes of schistosity, which are usually observably identical with those of bedding; at times the agglomerates merge into mica schists on the one hand and into hornblende schists on the other. The mica schists, micaceous slates, clay slates, and quartzites constitute a natural group of rocks intimately associated, both as regards their origin and their present relations in the field. They are all probably ordinary metamorphic clastics. The felsitic, sericitic, and hydromicaceous schists are probably sediments, the material of which was probably volcanic. The mica schists frequently pass into finely laminated mica gneisses. The limestones are found only in small masses and seem to be vein stones rather than bedded strata.

The Keewatin schists and Laurentian granitoid gneisses are in many places apparently interbedded; in other places the junction is of the most irregular sort, tongues of schists running into the granite, or masses of it being contained in the granite and gneiss. The gneiss acts in many places as though it had in a fluid state intruded the schists, and the conclusion is reached that the junction, instead of being that of interlaminated sediments, is that of a set of schistose rocks which have been intruded by fluid ones, the fluid material often placing itself along the parting of the schist, at other times cutting across it or including fragments of it. If this conclusion is true, the supposed conformable junction of the two series at certain localities is no proof of true conformity, because the foliation of the granitoid gneisses, if these rocks were once viscid or plastic, is quite independent of any arrangement due to sedimentation that they may have possessed. This conclusion does not imply that the gneisses and schists may not have been originally sedimentary and conformable. However, the author inclines to the belief that the granitoid gneisses of the Laurentian were never aqueous sediments.

The granitic intrusions of the Lake of the Woods are grouped into ten main centers. The granite cuts both the granitoid gneiss (Laurentian) and the various rocks of the Keewatin series, and is therefore of later age than either. A granite, the intrusive character of which is undoubted, sometimes in the same rock mass merges into a granitoid gneiss. There is a marked association of felsites or microgranites with the main granite mass, there being an apparent tendency on the part of the former to an arrangement concentric with the periphery of the granite. In various sections a certain periodic arrangement of the Keewatin is made out, upon which as a basis it is found that the maximum thickness of the series is in the neighborhood of 20,000 feet. As to the general stratigraphical relations of the Keewatin, the conclusion is reached that the beds have been laid down and folded within a trough in the Laurentian formation.

Herrick, Tight, and Jones,[248] in 1886, find on the north shore of Lake Superior three distinct groups of rocks with their respective intrusives, granitic, schistose, and conglomeratic. The granites are found underlying the schists in such a way as to suggest that they have been intruded beneath them, although similar granites constitute the pebbles of the basement conglomerates in the schists. The schists are metamorphosed at contacts with the granites; the schists and schist conglomerates especially, in several places, have been altered to porphyry and felsite porphyry by contact with the eruptives. The third group consists of basement conglomerates, containing fragments of all the verieties of rock included in the other two series. Periodic overflows of igneous matter have left vast sheets of diabase, and there is a strong interaction between the sedimentary and eruptive rocks.

McKellar,[249] in 1888, describes the Animikie on the north shore of Lake Superior as always resting unconformably upon the crystalline and schistose rocks to which the term Huronian is applied, the contacts being found at many points. In lithological characteristics these two series are fundamentally different. The original Huronian and the schists underlying the Animikie are compared, and it is concluded that they are the equivalent of these rocks rather than of the Animikie series; therefore the latter is later than the Huronian. The contacts of the Animikie and Keweenawan formations show that there is an unconformity by erosion between the two.

Lawson,[250] in 1888, reports on the geology of the Rainy Lake region. The pre-Cambrian rocks are divided into an upper and a lower Archean, as at the Lake of the Woods. The upper is a bedded schistose and metamorphic series, while the lower is granitic, gneissic, or syenitic in character. In the upper division two groups are recognized, one the Keewatin of the Lake of the Woods, and the other, inferior in position, is given the name Coutchiching. In the lower division distinctions of stratigraphical sequence and relationship, if any such ever existed, have been obliterated, and for this the term Laurentian is retained. These rocks can be classified only on a petrographical basis. The contacts of the Keewatin with the Coutchiching and Laurentian are very numerous. The relations between the Keewatin and Laurentian are exactly like those described as existing at the Lake of the Woods. The schists are intruded by the granite, fragments of the former being included in the latter, and they are sometimes fused at the contact. Very frequently near the point of junction the Keewatin rocks become more crystalline and are glistening hornblende schists.

At two localities basal conglomerates are found between the Keewatin and Coutchiching. At the first of these, Ratroot Bay, Keewatin conglomerate rests upon Coutchiching schists, the conglomerates containing waterworn fragments of quartz and bowlders of granite. The second is at Grassy Lake, where there is a pebbly conglomerate at the base of the Keewatin. The contacts of the Keewatin and Coutchiching are usually in apparent conformity, and the mapping of the series is made to rest upon lithological characters rather than upon structural discordance, although it is recognized that the conglomerates at the two localities mentioned are indicative of erosion, at least in some places, between the two series. The apparent accordance affords little evidence as to the question of original conformity or unconformity, because the two formations have been squeezed together; but the marked contrast in lithological characters indicates an abrupt change in the conditions of formation.

The thickness of the Keewatin rocks is calculated to be about 5 miles. The rocks are found in the main to be of clastic origin, but probably in the nature of volcanic débris rather than water-deposited sediments, although a small quantity of the materials is of the latter character. The volcanic débris of the Keewatin has a basic and an acidic division, the latter being higher in the series than the former. Microscopic study leads to the conclusion that the series has been subjected to a great pressure, as is evidenced by the fracture of the grains as well as by the schistose structure. The granite bowlders found in the conglomerates may either be ordinary detritus or have been brought up from beneath by volcanic forces, although the former is the more probable. All of the granites of the region appear to be in some degree later than the Keewatin rocks, but this does not imply that there was not a granite shore for the basin in which the Keewatin rocks were deposited. The author has no doubt that the original floor upon which the Keewatin and Coutchiching rocks were deposited was fused at the time of disturbance and appears now to us as the foliated granite of the Laurentian. The granite bowlders of the Keewatin agglomerates may have been derived from a granite basement obliterated by subsequent plutonic fusion.

The Coutchiching series consists of mica schists, or mica schists in which feldspar is present. Hornblende has been observed only in one instance. No limestones or conglomerates have been discovered. The schistose structure is believed to represent original sedimentation. Upon this basis the formation has an average thickness of 4 or 5 miles. The relations of the Coutchiching series to the Laurentian are found to be precisely the same as between the Keewatin and the Laurentian. In the Coutchiching series there are no intercalations of recognizable volcanic rocks such as are found in the Keewatin, the rocks being acidic crystalline schists which are regarded as ordinary metamorphosed quartzose sediments, with perhaps also volcanic material, although in no place has it been possible conclusively to prove this.

The Laurentian gneiss is intermixed with granite in such a way as to make it impossible at times to separate them. Its structure, if it has any, is so complex that no attempt was made to work it out, and, while parts of the granite seem to belong to the Laurentian proper, it is certain that granitic eruptions have occurred in this series after the main mass of the rock had solidified. The belts of Keewatin rocks which encircle the Laurentian areas are anastomosing or confluent, forming a continuous retiform area, the meshes being occupied by the Laurentian gneiss. At their nodes or points of confluence these belts have their greatest width. The Coutchiching schists dip away from the Laurentian bosses in all directions, so that the general anticlinal structure of the belt is made up of three anticlinal domes. These relations are taken to mean that the surrounding schistose rocks represent sedimentary beds which have been thrust aside by the entering granite. Along the contacts of the Laurentian and Coutchiching are found such minerals as andalusite, staurolite, and garnet. Besides the granite masses, which cut all three of the previous series and thus are later than all, are also numerous diabase and trap dikes, which cut the series mentioned and the granite besides.

Ingall,[251] in 1888, in describing the mines and mining of Lake Superior, finds the rocks to consist of Laurentian gneisses and granite, within which are found considerable areas of plutonic and volcanic rocks and metamorphic slates, considered to be Huronian, while overlying these, chiefly about Thunder Bay and Lake Nipigon, are the sedimentary and volcanic rocks of the Animikie, Nipigon, and Keweenian groups, which are in an approximately horizontal position and contrast markedly with the steeply inclined or almost vertical older rocks. The Animikie formation is divisible into an upper and a lower portion. The chief character of the lower division is the preponderance of siliceous rock, such as chert and jasper, which are often accompanied by ferruginous dolomite with magnetite; while the upper division is formed for the most part of black, soft, argillaceous argillites, which are occasionally dolomitic and ferruginous, and sometimes contain silica in such proportion as to approach the character of the lower division. The thickness of the Animikie is placed at 12,000 feet. The traps of the Animikie are concluded to be intrusive, frequently breaking as they do across the beds. In one case a sheet is seen to divide into three tongues. The dark color of the upper division of the Animikie is due to the presence of carbon. Patches of basal conglomerates are occasionally found at the base of the Animikie, lying in hollows in the old Archean sea bottom, the fragments consisting in general of granitic material.

Selwyn,[252] in 1890, announces the discovery by Ingall of traces of a fossil in the Animikie rocks. A part of the impressions are pronounced by Matthew to be similar to *Eophyton*, while for others the names *Taonichnites* and *Ctenichnites* are proposed. Some of them are of similar origin with characteristic tracks in the Cambrian rocks of the St. John group of New Brunswick.

Lawson,[253] in 1890, discusses the internal relations and taxonomy of the Archean of central Canada. The Keewatin and Coutchiching are again described, and the characteristic contacts which they have with the Laurentian. To the upper division, the Keewatin and Coutchiching, since they are sedimentary rocks, the principles of stratigraphical geology apply, and to cover these two series is proposed the term Ontarian, of systemic value. The principles applicable to the lower division, the Laurentian, are those of eruptive geology, since these rocks are of igneous origin. In the Laurentian there are at least two generations of rocks which are distinguishable in the Hunter Island district, but both are the result of the crystallization of a subcrustal magma.

Bell,[254] in 1890, gives the following as the chief Huronian areas about Lake Superior, in Ontario. An important area lies around Michipicoten, at the northeast angle of Lake Superior, running for 60 miles west and 20 miles south of that point, and extending inland to Dog Lake, a distance of 45 miles. Another large area stretches from Pic River eastward or inland to Nottamasagami Lake, and westward, mingled with granites and greenstones, to Nipigon Bay. Two extensive belts run eastward from Lake Nipigon, one of which crosses Long Lake. West of Thunder Bay, and stretching to the international boundary line, is a large area which gives off arms to the northeast and the southwest; and several belts and compact and straggling areas occur between this and the Lake of the Woods basin, one of which follows the course of the Seine River. The Lake of the Woods area occupies the whole breadth of the northern division of that lake. An important belt starts between Rainy Lake and Lake of the Woods, and running northeastward has a breadth of 45 miles where it crosses the line of the Canadian Pacific Railway. Minnietakie and Sturgeon lakes lie within this belt.

The Huronian is divided into a lower and an upper division, although no horizon has been agreed upon at which to draw the line between the two even locally. There is no evidence whatever that the two divisions are unconformable or that the lower part of the upper division consists of basal conglomerates. Conglomerates are found indifferently throughout both lower and upper divisions.

The lower division includes the Keewatin of Lawson and its equivalents. It consists largely of a variety of crystalline schists, in which the prevailing color is dark green or gray. Among these may be enumerated micaceous, dioritic, chloritic, argillaceous, hornblendic, talcoid, felsitic, epidotic, siliceous, dolomitic, and plumbagenous. There are also crystalline diorites or diabases of various shades of gray and greenish gray (mostly dark), argillaceous and dioritic slate conglomerates, granites and syenites, impure, banded, and schistose iron ores, dolomites, and imperfect gneisses. Among the commoner of the rocks of this division are fine-grained mica schists and dark-green dioritic or hornblendic schists. Two kinds of conglomerates are also abundant, one having an argillaceous matrix with rounded pebbles of syenite and granite of various kinds, and some of the other Huronian rocks, but very seldom of gneiss; the other with a dioritic matrix, and often with rounded pebbles also. But, in perhaps the majority of cases, what were formerly considered as pebbles are concretions of a lenticular form, and differ but slightly from the matrix in color and composition. They are best seen on wetted surfaces of cross sections of the rock, where they appear as parallel elongated patches tapering to a point at each end. Both hematite and magnetic iron ore are common in these rocks. Gneiss is not common in the Huronian, and it differs from the ordinary Laurentian gneiss in being imperfectly and slightly calcareous.

In the upper division of the Huronian is probably the most abundant rock in Ontario, which may be called a graywacke, but which in the older reports was often styled a "slate conglomerate;" but it also includes clay slates, argillites, felsites, quartzites, ordinary conglomerates, jasper conglomerates, breccias, dolomites, serpentine, etc. In some localities the nearly vertical bands of quartzite, having withstood denudation better than the other rocks, remain as conspicuous hills or ridges, and this circumstance has caused their relative volume in the series to be overrated by superficial observers. The materials forming the graywackes and the stratified quartzose diorites have been derived from volcanic sources. The igneous character of the Huronian is further shown by the large masses and areas of greenstone (diorites or diabases), granites, syenites, and other eruptive rocks which are so largely mingled with both the lower and the upper portions of the Huronian system in all parts of their distribution, forming indeed one of its characteristic features. The crystalline greenstones occur either as compact areas, wide elongated masses, dikes, or thick interstratifying beds in nearly all the Huronian areas. In many cases the dioritic schists may have been originally massive, but assumed the cleaved structure by pressure when incorporated among stratified masses. The commonest position of the granite and syenite areas is within but toward the borders of the Huronian tracts; but they sometimes occur in the Laurentian country, in the immediate vicinity of the Huronian tracts, or at a distance from them in the direction of the longer axis of the Huronian areas.

Unconformably above the Huronian is the Cambrian system, which comprises, in ascending order, the Animikie, Nipigon, and Potsdam formations.

The Animikie formation consists, in ascending order, of arenaceous conglomerate, with pebbles of quartz, jasper, and slate seen on the north shore of Thunder Bay; thinly bedded cherts, mostly of dark color, with argillaceous and dolomitic beds, and black and dark argillites and flaggy black shales, with sandstones and ferruginous dolomitic bands and arenaceous beds, often rich in magnetic iron, together with layers and intrusive masses of trap (diabase). The Animikie formation occupies a great triangular area north and west of Lake Superior, the base of which is 60 miles in length and the arms 40 and 80 miles, respectively.

The Nipigon formation, resting with apparent unconformity upon the Animikie formation, is characterized by reddish marls, sandstones, and conglomerates, with a large proportion of variously colored trappean beds and masses, a considerable part of which is amygdaloidal. The Nipigon formation occupies a great area about Nipigon Lake and considerable areas at the east end of Lake Superior and on Michipicoten Island.

On the east side of Hudson Bay and on the islands off the coast volcanic and sedimentary rocks are largely developed, comprising conglomerates, sandstones, limestones, chert breccias, shales, quartzites, argillites, porphyries, crystalline traps, amygdaloids, tuffs, etc. The upper part of these may correspond to the Nipigon and the lower to the Animikie.

The sandstones of Sault Ste. Marie, of the peninsula between Goulais and Batchawana bays, Isle Parisienne, etc., seem to be of Potsdam age. These sandstones are mostly red, but, unlike the Nipigon formation, they appear to be free from local disturbance and lie almost flat. Although they resemble some of the sandstones of the Nipigon series at Mamainse in red color, they are believed to be newer and probably unconformable to them.

Lawson,[255] in 1891, states that the granite of Saganaga Lake is found with abundant and clearly observed evidences of eruption, breaking through the Keewatin rocks, including the upper Vermilion fragmental rocks of Ogishki Lake with their associated slates and grits. It is concluded that the break between the upper and lower Vermilion, described by Van Hise, is within the Keewatin group, dividing it into an upper and a lower series, and that this break is therefore below the Animikie. It is further said that the conglomerates of the upper Kaministiquia series come out close to the shores of Thunder Bay and form the basement upon which the undisturbed Animikie rocks rest with strongly marked unconformity. The following succession for the region northwest of Lake Superior is presented: Keweenawan or Nipigon group; unconformity; Animikie group (possibly Huronian); unconformity; upper Keewatin series; unconformity; lower Keewatin series; unconformity (?); Coutchiching group; eruptive unconformity; Laurentian system, the granites and gneisses of which cut both Keewatin and Coutchiching groups.

Smyth (H. L.),[256] in 1891, describes the structural geology of Steep Rock Lake, Ontario. The lake is roughly in the shape of a letter M, the top is to the north, and its arms conform to the strike of the rock series. The rocks are divisible into three principal groups. The lower consists of granites and gneisses, and is designated the Basement Complex. Resting upon the Basement Complex is a series of rocks about 5,000 feet in thickness, composed of nine persistent formations, which together constitute the Steep Rock series. Lying across the edges of the Steep Rock series, at the southeastern part of the lake, is a later series of granites, porphyries, and hornblende rocks, which pass upward into the schists of Aticokan River and are designated the Aticokan series. The granites and gneisses of the basal complex are cut by various dikes, which are of three kinds—those which supplied pebbles to the conglomerate at the base of the Steep Rock series; those which traverse both the Basement Complex and the Steep Rock series but have been subjected to the folding; and, third, a single massive dike which is subsequent to the latest period of folding.

The formations of the Steep Rock series are, in ascending order, conglomerate, lower limestone, ferruginous horizon, interbedded crystalline traps, calcareous green schists, upper conglomerate, greenstones and greenstone schists, agglomerate, and dark-gray clay slate. It is, then, a series of sediments and interbedded eruptives.

Along the whole course of the lake this series dips at very steep angles, ranging from 60° to 80°, away from the basement rocks, upon which they hang as a time-worn fringe having no extension inland. The basal part of the Steep Rock series is a bed having a maximum thickness of nearly a hundred feet, presenting the various phases of a conglomerate, coarse and fine, and quartzite and quartz schists with feldspar. The lowest member contains rounded and waterworn pebbles of quartz and greenstone, the largest being a foot in diameter. Near the junction of the Steep Rock series and basal complex both are sometimes very similar in composition, so that it is impossible to draw the lines between them by this criterion. There is an apparent transition from one rock into the other. The transition zone has a highly schistose structure in the regional direction, which crosses the course of contact and the bedding nearly at right angles and is traced from the transition zone into the undoubted granite, into which it gradually dies out. This transition is explained as due to probable disintegration of the Basement Complex before the Steep Rock series was deposited, combined with subsequent powerful dynamic movements which have affected both series.

The Steep Rock series is folded into an eastern syncline, a middle anticline, and a western syncline, the latter being faulted. The axes of these folds have a high pitch to the south, varying from 60° to nearly 90°. Throughout the whole area is a regional cleavage which has a nearly uniform direction transverse to all the members of the Steep Rock series and also to the contact between this series and the Basement Complex. This has largely obliterated the original lamination of the sediments and is now the dominant structure. It is therefore the last force which has left its marks upon the rocks of the lake. Before this last force acted upon the rocks, the Steep Rock series had been folded into a southwestward-dipping monocline, which, under the action of the cleavage-producing force in a northeast-southwest direction, caused the present fluted outcrop of the formations of the Steep Rock series. That the Basement Complex itself yielded to this latter force is shown by the irregular outcrops of the dikes cutting it.

As a result of the study the following general conclusions are reached: The contact of the lowest horizon of the Steep Rock series with the Basement Complex is one of erosion. The complex at the time of the deposition of the Steep Rock series was made up of consolidated crystalline rocks, and there is no evidence whatever that it has since undergone fusion or recurred to the condition of a magma. The rocks of the Steep Rock series have been subjected at two periods, more or less distant from each other, to great orotechnic forces, which acted, the first in a northeast-southwest direction and the second in a northwest-southeast direction. The latter force has imposed upon all the rocks of the region a northeast structure which has largely, but not entirely, obliterated preexisting lamination in the sediments and schists of the Steep Rock series. The two orotechnic actions have produced great developments of autoclastic schists, both in the granites and in the rocks of the Steep Rock series, the present structure of which was induced and determined in direction by the later force.

Smith,[257] in 1892, reports on the Archean rocks of Hunters Island and adjacent country. The rocks are divided into Laurentian and Huronian, and the latter are subdivided into Coutchiching and Keewatin. The main occurrences of the Laurentian rocks are the Kawagansikok, Poo-Bah, Hunters Island, and Saganaga areas. The Kawagansikok granite is in places fine grained and nearly devoid of mica and hornblende; in other places, a muscovite granite; in others, garnetiferous granite gneiss. The rock is in many places cut by coarse pegmatite veins. The Poo-Bah area is usually a coarse hornblende syenite, but in places it merges into a finer grained hornblende granite. The Hunters Island rocks are usually biotite granites, but the biotite is often replaced by or associated with muscovite, hornblende, or chlorite. At Agnes Lake angular fragments of mica schist or gneiss are found in the granite. At various places occur hornblende granites. There are other isolated areas of granite which break through the Coutchiching rocks which can not certainly be said to be of Laurentian age. The granites as a whole usually have a foliated character.

The Coutchiching series covers a large area in the northwestern part of the district, and several small areas are found to the east. The Coutchiching rocks are usually mica schists. In general their schistosity is parallel to that of the granites, but at Conmee Lake there is a discrepancy between the two which may indicate a structural unconformity or a fault. The mica schist is cut by granite apophyses at various places. If foliation is taken as thickness the series would vary from 1.386 to 5.548 miles. However, the mica schists are regarded as repeated by folding. Although having isoclinal dips, there is a considerable variation which may indicate such folding.

Keewatin rocks are confined to the southeastern part of Hunters Island. They consist of quartzites, soft gray schists, quartz porphyries, felsite, sericite schists, conglomerates, altered traps, hornblende schists, and other green schists. Occasionally contained in them are areas of banded jasper and hematite. On the north side of Cache Bay is a felsitic conglomerate in contact with a coarse-grained hornblende granite. Beds of dolomite are associated with this conglomerate. The breadth of the Keewatin series gives no certain criterion by which to estimate its thickness. The dip shows an apparently simple synclinal structure.

As to the relations of the Laurentian to the Huronian series, they have a general parallel schistosity, and there are many phenomena suggestive that the granitic and syenitic type is of igneous eruptive origin, later than the Huronian, but the hornblendic and micaceous phases of these granites may be rocks of different determinable ages, the discovery of which may throw light not only on the genesis of the Laurentian but on its relations to the overlying Coutchiching and Keewatin. Cutting both Laurentian and Coutchiching rocks are diabase dikes in such attitudes as to leave little doubt that they were intruded since the last folding, on which assumption their geological age is post-Keewatin.

Lawson, in 1893, gives a petrographical and structural account of the anorthosites of the northwest shore of Lake Superior. See summary in section 3, Minnesota, pages 215–216.

Smith,[258] in 1893, gives a general description of the Archean rocks in the southern half of the Rainy Lake district in the Province of Ontario, between the Thunder Bay district and the Lake of the Woods. The rocks here found are divided into Lower Archean and Upper Archean, the term Archean being defined to include all pre-Cambrian rocks. The Lower Archean series, or Laurentian, comprises a lower granitic and syenitic division and an upper micaceous, hornblendic, and trappean division, for the most part schistose. The first usually occurs in rounded or ovoid areas, between which are the rocks of the Upper Archean or Ontarian.

The Ontarian system includes the Coutchiching and Keewatin series. The Coutchiching rocks are mainly mica schists, and have an estimated thickness of 9,000 feet, the apparent thickness of 24,000 to 29,000 feet, given by Lawson, being believed to be due to multiple folds. These mica schists are regarded as clastic in origin, because of their fine and even lamination. The Keewatin consists for the most part of plutonic, volcanic, and pyroclastic rocks, although in some of the upper members there are more or less aqueous sediments. The Coutchiching and Keewatin are everywhere in strict conformity, although at the base of the Keewatin in certain localities there are conglomerates regarded as local and volcanic.

The Laurentian granites and gneisses are intrusive in the Ontarian, and are therefore younger, the relations between the two being the same as described by Lawson in the Rainy Lake district.

Resting discordantly upon the Laurentian and Ontarian rocks is the Steep Rock series, presumably of Archean age. This series is believed to be a folded syncline, rather than a monocline, as described by Smyth. As the Animikie series exhibits no such folding, the inference is strong that the Steep Rock series is older than the Animikie. While the unconformity between the Steep Rock series and the Laurentian is undoubted, the unconformity between the Keewatin of Seine River and the Steep Rock Lake series is not at all obvious. Lithologically the two series are strikingly similar, and could not be separated by the most careful study. It would seem that to the west of Steep Rock Lake this series has been faulted up and swept away, so that it is really unconformably above the Keewatin. The Atic Oban series is an eruptive one, probably belonging to the Keewatin.

Lawson,[259] in 1893, describes the laccolithic sills of the northwest coast of Lake Superior. The trap sills are mainly diabases, but they occasionally pass into gabbros. It is held that there are no contemporaneous volcanic rocks in the Animikie group, and that the trap sheets are intrusive in origin, rather than subsequent volcanic flows, for the following reasons: They are simple geological units, one not overlapping another; they have a uniform thickness over areas more than 100 square miles in extent; where inclined, the dip is due to faulting and tilting; they have no pyroclastic rocks associated with them; they are not glassy nor amygdaloidal; they show no flow structure or other distinct properties of effusive rocks; their contacts with the slates are sharp; they never repose upon a surface which has been exposed to weathering or erosion; they are analogous to the great dikes of the region in all their relations; they may be observed in direct continuity with dikes; they pass from one horizon to another; they have a columnar structure extending throughout their thickness; apophyses pass from the main sheets into cracks of the slate above and below; they locally alter the slates above and below them.

The Animikie strata have been dislocated by a great system of faults, the orographic blocks having been frequently tilted. The nonrecognition of this prevalent tilted structure has led to very excessive estimates of the thickness of the series by Irving and Ingall. In the vicinity of Black Sturgeon River and on the isles of Nipigon Bay are numerous places where Keweenian strata are capped by thick sheets of trap, identical with those which cap the Animikie, but, though these sheets can not be traced in absolute continuity in the interval, there are many outlying patches which fill the gap. The same trap sheets are found in several instances to pass from the Animikie to the Keweenian, and there are the same evidences of intrusion of independent trap sheets in the Keweenian that there are in the Animikie. These rocks are, therefore, of post-Keweenian age, and, to discriminate them from the Keweenian and Animikie, they are designated the Logan sills.

LAWSON,[260] in 1894, describes a multiple diabase dike near the mouth of White Gravel River, on the northeast coast of Lake Superior, where occur in a breadth of 14 feet no fewer than twenty-eight vertically intrusive sheets of diabase, ranging in thickness from 1 inch to 6½ inches, separated by twenty-seven sheets of granite, ranging in thickness from one-fourth inch to 8 inches. The dikes anastomose and are connected at various places, showing that they are due to a single intrusion. The granite is seemingly homogeneous, there being no differentiation of structure or of mineral composition. It is believed that the splitting of the granite was due directly to the invasion of the diabase magma. This occurrence is comparable to the complex parallel invasion of the schistose rocks of the Ontarian system by granite.

GRANT,[261] in 1894, describes the lowest beds of Grand Portage Island, north coast of Lake Superior, as consisting of arenaceous slates, sandstones, and conglomerates, the fragments of the latter being quartz, quartzite, siliceous slate, a dark flinty rock, red quartz porphyry, and red granite. These are in part clearly waterworn. All of the pebbles of the conglomerate can be matched in the Animikie strata near by. These beds are regarded as the lowest of the Keweenawan in this locality, and the material in the conglomerate shows that the Animikie clastics had been subjected to metamorphosing forces before Keweenawan time and, as agreed by all Lake Superior geologists, that there was an erosion interval between the two. As the red quartz porphyry and the granite have been shown to be intrusive in the Animikie, and also in the gabbro and diabase of Pigeon Point and Grand Portage, it is concluded that these intrusions occurred at a date earlier than the Keweenawan.

COLEMAN,[262] in 1895, gives a summary of the geology of the Rainy Lake region. Following Lawson, he classifies the rocks as follows:

Archean	Upper division.	*a.* Keewatin (Huronian?).
		b. Coutchiching.
	Lower division.	Laurentian.

The Laurentian rocks consist chiefly of granite gneisses with subordinate quantities of granite and syenite. The Coutchiching consists of fine-grained mica schists and mica gneisses, which show rapid changes in composition in passing from one layer to another, thus suggesting sedimentation. These rocks are usually sharply separated from the Laurentian, but at Rice Bay the writer found himself in doubt as to the classification. The Coutchiching series is regarded as a metamorphosed sedimentary one. As to the source of the material there is no very definite information, unless certain gneisses in Sand Island River having layers differing sharply in composition be looked upon as remnants of an original Laurentian floor. The Keewatin is a series of eruptive and fragmental rocks of great thickness and variety, consisting broadly of a lower division of basic eruptives and volcanic ashes and of an upper acidic division. The bulk of the lower, basic portion consists of diabases with some gabbros and anorthosites, and apparently some diorites. Porphyroids are also present. The schistose members, often interbedded with the massive altered eruptives, near the contact with the Laurentian are chiefly hornblende schists, but in other localities are chlorite schists. Between these two are numerous transitions. Graywackes occur at several localities, and agglomerates and conglomerates are plentiful. The upper, acidic division includes felsites, sericite schists, and quartz porphyries. These are apparently younger than the green schists and massive rocks of the Keewatin, but the two divisions are conformable, as is also the whole of the Keewatin to the Coutchiching. The rocks included in the Laurentian are, for the most part at least, intrusive in the Coutchiching and the Keewatin. In the Keewatin are various intrusive granite areas. Cutting all of the previous series are dike rocks, which may be regarded as consisting of an acidic division, including granite and pegmatite, and a basic division, including diabase and quartz diabase.

Many details are given as to particular occurrences of the various rock series. The occurrence of gold in Ontario is described, and incidentally the rock succession in the Hastings district is summarized.

GIBSON,[263] in 1895, gives a summary, from the reports of the Canadian Geological Survey, of the pre-Cambrian geology of the Hinterland of Ontario.

BLUE,[264] in 1896, sketches the geological history of the New Ontario, which includes that part of the Province of Ontario lying beyond Matawan and French rivers and the Nipissing, Huron, and Superior lakes, to the north and west boundaries of the province. Laurentian and Huronian rocks form highlands which in Archean time were the most important physical feature of North America, sweeping in a curve through what is known in our time as the regions of Labrador, Quebec, Ontario, and the Northwest Territories. While there are large areas in which eruptive masses of granite and gneiss have penetrated the Huronian rocks, and thrown them into folds, proving their later age, in general the reverse is the case, the Huronian resting unconformably upon the Laurentian and being of later origin. The Huronian is overlain unconformably by Cambrian rocks, under the Cambrian being included Animikie, Nipigon, and Potsdam rocks.

Coleman,[265] in 1896, makes a second report on the gold fields of western Ontario, including the area between Finmark, near Thunder Bay, and the Manitoba boundary, and between Minnesota and Keewatin, on the north shore of Lonely Lake. This visit confirms his impressions of the geology of the area as given in the preceding report of the bureau.

At many places the Laurentian rocks exhibit an eruptive contact with the overlying rocks, showing that they must have been consolidated later than the Huronian. Coleman suggests that it would be more logical to confine the name Laurentian to the oldest complex of thoroughly crystalline rocks serving as a foundation for all succeeding rocks, and to describe the clearly eruptive rocks which penetrate the overlying Huronian schists as eruptives, of later age than at least the earlier members of the Huronian. If this were done, very little of the territory under consideration could be mapped as Laurentian; perhaps none of it with certainty. However, the discrimination may not be made until more detailed work has been done in the district.

Coutchiching mica schists and gneisses, though probably present, have not been certainly recognized. The series of eruptives, pyroclastics, and less common waterworn clastics, Lawson's Keewatin, is of widespread occurrence, and of great importance as containing the gold-bearing veins of the district. It is spoken of under the general term Huronian.

Coleman,[266] in 1896, describes the anorthosite of the Rainy Lake region. The granite found adjacent to the anorthosite in the neighborhood of Bad Vermilion Lake is of considerably later age than the anorthosite. A schist conglomerate containing fragments of the latter is found to be intruded by the granite.

Lawson,[267] in 1896, describes a family of basic plutonic orthoclase rocks rich in alkalies and lime, which he names malignite, as occurring in the form of a laccolith in the Coutchiching schists of Poohbah Lake. The malignites vary from basic nepheline-pyroxene malignite through garnet-pyroxene malignite to amphibole malignite.

Coleman,[268] in 1897, makes a third report on the gold region of western Ontario. The districts visited and here reported on are the Upper Seine district, the Shoal Lake district, the Manitou district, the country crossed between Manitou Lake and the Lake of the Woods, the Lake of the Woods district, the West Shoal Lake district, the neighborhood of Rat Portage, and the vicinity of Fort William on Lake Superior. As in previous reports, the general geology worked out by Lawson for the Lake of the Woods and Rainy Lake districts is accepted, and the general principles are applied to other districts of the region visited.

In previous years it has been held that gold was to be looked for only in the Huronian. During the last three years, however, it has been found that some of the most promising gold deposits occur in the granite or the gneiss. It has also been found that the best veins or other ore deposits occur at or near the contact of the Laurentian eruptive rocks and the Huronian.

In the Ontario region the gold deposits occur in the following ways: (1) True fissure veins, commonly found in the areas of massive eruptive granite. (2) Lenticular or bedded veins, confined to the schistose rocks. These are intercalated between the schists and run parallel with their strike, and are not so continuous as the fissure veins. (3) Contact deposits, between the Huronian and the Laurentian. These are rare in this district. (4) Fahlbands of schists, impregnated with pyrites and other sulphides. (5) In quartz, associated with dikes of porphyry or felsite, near the contact of the Huronian and Laurentian rocks, penetrating the schists, and sometimes the granite itself. (6) In an eruptive mass, in but one locality. (7) Placer deposits.

Willmott,[269] in 1898, describes the geology of the Michipicoten mining division, which is limited on its eastern side by the 84th meridian, on the west by Lake Superior, on the south by latitude 47° 30′, and on the north by latitude 48° 30′. Most of the rocks of the area belong to the Laurentian and Huronian. The northern, eastern, and southeastern portions of the area are occupied by the Laurentian; the central and southwestern portions by the Huronian. The Laurentian is almost everywhere a fine-grained gray gneiss, which often becomes granitic and coarser grained in texture. The Huronian rocks are most commonly massive diorites and diabases and hornblende and chlorite schists; less commonly they are slates, felsites, quartzites, and sericite slates. The Laurentian is frequently in eruptive contact with the Huronian.

In two areas the Nipigon or Keweenawan rocks overlie the Huronian and Laurentian rocks. One of these areas is 2 miles north of Cape Choyye, and the other is on the peninsula of Gargantua.

Parks,[270] in 1898, describes the geology of the base and meridian lines in the Rainy River district, in an area extending from Lac Seul on the northwest and Lake Wabigoon on the southwest to Sturgeon Lake and Mattawa Lake on the east. Laurentian and Huronian rocks occur in folds with a general northeast-southwest trend. The Huronian rocks occur in three main areas—the Sturgeon River area, the

Lake Minnetakie area, and the Wabigoon Lake area. They consist of altered traps, hornblende schists and other green schists, altered porphyrites, quartz porphyries, phyllites, and conglomerates. In general they resemble Lawson's Keewatin series to the south. The Laurentian consists of hornblende-syenite, hornblende granite gneiss, mica syenite, biotite granite gneiss, and various granitic rocks.

Coleman,[271] in 1898, gives an interesting general account of the clastic Huronian rocks of western Ontario, in the region extending from the Lake of the Woods on the west to Mille Lacs on the east, a distance of 200 miles, with a width north of Rainy Lake of 120 miles. The Huronian, including the Keewatin and Coutchiching rocks, is in general an immense series of waterworn sediments, in the upper part mixed with eruptives, perhaps largely later injections, but partly pyroclastic. The Keewatin is largely of eruptive origin, though it contains important sedimentary members; the Coutchiching is entirely sedimentary.

The Keewatin, and in the southern part of the region the underlying Coutchiching, form sharp synclines, curving as wide meshes around the areas of Laurentian, which vary from less than a mile to 50 miles in diameter.

Diabase and porphyry eruptives form an important part of the Keewatin. These are in large part surface flows, represented by ash rocks, agglomerates, etc., but many of them are probably laccolithic sills. The water-formed clastics of the Keewatin include limestones, slates, quartzites, grits, graywackes, breccias, and pebble and bowlder conglomerates. The limestones are of limited extent, being found in any thickness only at Steep Rock Lake. The slate on analysis yields 7.44 per cent of carbon, pointing perhaps to the presence of life. The conglomerates are in places schistose. Near Shoal Lake the most common pebbles are quartz porphyry and porphyrite, felsite, and green schists indistinguishable from the adjoining Keewatin schists; black and red quartzite, white pulverulent sandstone, vein quartz, and anorthosite. No gneiss or granite pebbles have been found. Most of these pebbles are easily matched by Keewatin rocks, sometimes, however, many miles distant; a few are evidently Coutchiching, and none are Laurentian.

The break represented by this conglomerate comes high up in the Keewatin, instead of at its base, just above the Coutchiching, as held by Lawson. Striking evidence that the break is not at the base of the Keewatin is found at Shoal Lake, where a few bowlders of the coarse-grained anorthosite found in the schist conglomerate are exactly like portions of a boss of anorthosite 2 miles away. As this anorthosite area contains masses and strips of characteristic Keewatin schist, swept off during its eruption, it is evident that an immense lapse of time separates the conglomerate and the underlying Keewatin. It is probable that the conglomerates represent an important interval of erosion, perhaps equivalent to the one shown by Van Hise and others between the Upper and Lower Huronian in the States to the south.

The Coutchiching rocks are all formed of clay sand, more or less metamorphosed; in general they are biotite schists or gneisses, the quartz showing a clastic origin. The Coutchiching passes up by transition into the Keewatin, and there is no reason why the two together should not be classed as Huronian.

Following Lawson's estimate, the Keewatin and Coutchiching series together sum up 50,000 feet in thickness.

The term Laurentian is employed, as Lawson and other Canadian geologists are accustomed to employ it—in a petrographical and structural sense—for crystalline gneisses and granites underlying the Huronian, although it is evident that these rocks have consolidated at a time later than the Huronian.

As described by Lawson, the Laurentian (Lower Archean) "occurs in large isolated central areas, more or less completely surrounded by the schists of the upper Archean, the encircling belts anastomosing and forming a continuous mesh work." It consists chiefly of a coarse reddish, often porphyritic rock, usually granite in the central part of the area, but showing a foliation, generally parallel to the periphery, where it comes in contact with the Huronian.

Throughout the region the Laurentian is in eruptive contact with the Huronian, and nowhere is a basal conglomerate of the Huronian found. Near the contact with the Huronian strips and fragments of the Huronian are embedded in the gneiss; also dikes of granite, pegmatite, or felsite generally run from the gneiss into the Huronian. The larger areas of gneiss and granite are evidently batholiths. Some of the smaller granite bosses may be stumps of old volcanoes. The Huronian schists usually dip rather steeply away from the gneiss, at an angle seldom less than 45°. Finer grained granites cut both the Keewatin and the Laurentian. However, it is not easy to say whether a given granite is Laurentian or a later granite.

It is believed that as a result of the piling up of a thickness of 8 or 10 miles of sediments and eruptive materials, represented by the Keewatin and Coutchiching rocks, the slowly rising isogeotherms softened or fused the foundation, which rose into domes, the inner parts solidifying as granite, and the outer, more viscid portions having their constituents dragged into rough parallelism with the adjoining solid rocks and forming gneiss.

As the Huronian rocks south of Lake Superior and in New Brunswick are described by Van Hise and Dawson as presenting basal conglomerates resting unconformably on the Laurentian, it is suggested that in these cases the thickness of the sediments was not great enough to depress the Laurentian floor to the level of fusion or plasticity; or that the Huronian, as recognized in these regions, is really younger and overlies the upturned edges of the rocks described as Huronian in the northern Archean.

VAN HISE,[272] in 1898, visited the Rainy Lake and Lake of the Woods districts. Observations made in the Shoal Lake area, along the south side of Rainy Lake, led to the conclusion that the Coutchiching is for the most part stratigraphically higher than the rocks mapped as Keewatin; in other words, that Lawson's succession should be reversed. The schists of the northern part of the lake, mapped as Keewatin, were found to be intruded by granites with normal intrusive contacts. No evidences of subcrustal fusion were observed.

McINNES,[273] in 1899, describes the geology of the Seine River and Lake Shebandowan map sheets, which cover an area extending west and northwest of Port Arthur, Ontario. Laurentian granites and gneisses with many variations occupy three-fourths of the area. The relations to the overlying Keewatin and Coutchiching rocks, wherever they have been found in contact, have been those of intrusion.

The Huronian is represented by Coutchiching and Keewatin rocks. Coutchiching mica schists and fine-grained gneisses, a continuation of Lawson's Coutchiching in the Rainy River district to the west, enter the area of the Seine River sheet on the west side. However, toward the east these rocks become associated with large quantities of gneisses, and for the eastern two-thirds of the Seine River area and for the entire Lake Shebandowan area the gneisses are predominant and the belt is mapped as Laurentian. In other parts of the district the Keewatin schists, near their contact with the Laurentian gneisses, assume a character exactly similar to the Coutchiching schists and associated gneisses, and could not be lithologically distinguished. Indeed, the Coutchiching seems to be an extremely altered phase of the Keewatin.

In long bands infolded with the Laurentian and conforming in strike with the foliation of the gneiss are Keewatin rocks varying greatly in width. They vary in composition from extremely basic igneous masses and their derived products to acidic quartz porphyries and their derived products, and include also quartzites, conglomerates, and slates. The basic rocks form the largest volume of the rocks of the series. The series is separated lithologically in mapping into three divisions. There can be no doubt that the Keewatin here includes rocks which are of widely differing age.

Overlying unconformably the Keewatin rocks is the Steep Rock Lake series, so named from its occurrence in the neighborhood of this lake. The series is mapped as an upper division of the Keewatin series. As described by Smyth it comprises conglomerate, limestone, clay slate, and various basic volcanic and intrusive rocks. Because of the folding of the series it is believed to be older than the Animikie strata of Thunder Bay.

Animikie rocks occur in a small area in the southeast corner of the Shebandowan region. They overlie unconformably the Keewatin and Laurentian rocks, and from their stratigraphical relations to the overlying formation farther east on Lake Superior they are believed to be of Lower Cambrian age.

Coleman,[274] in 1899, discusses areas mapped by Logan as Huronian north of Lake Huron and the east end of Lake Superior. The two contacts described by Irving and Van Hise as contacts of the Lower Huronian and Laurentian rocks were examined. At the first, on the islands 4 miles east of Thessalon, jasper and chert fragments were found in the conglomerate above the Laurentian, indicating that the conglomerate is probably a part of an upper series, younger than a series of rocks, not Laurentian, from which the jasper must have been derived. At the other contact, on the road between Sault Ste. Marie and Garden River, it is concluded that the conglomerate is possibly a crushed conglomerate formed by faulting, instead of a water-formed rock.

Certain green and gray schists inclosed in the Laurentian gneisses are believed to represent the western Keewatin of Lawson.

The Laurentian and Huronian contact at Goulais and Batchawana bays was found to be in general of the nature of an eruptive contact, although a clear example of the inclusion of a typical Huronian rock in the Laurentian was not observed.

The slate conglomerate of Dore River contains no bowlders that are distinctly Laurentian. It contains only fragments of schists and eruptives from rocks which have been called Huronian. It probably has closer affinities to Lawson's Keewatin than to Logan's Original Huronian.

On the shores of Heron Bay the schist conglomerate and slate were examined. The conglomerate contains fragments mainly of granite. These rocks are more closely allied to the Keewatin than to the Original Huronian type.

In general it is believed that Logan mapped as Huronian rocks which are really Huronian and Keewatin.

The ascending succession for the region as indicated by the above facts is as follows: Keewatin, consisting mainly of basic green schists; Laurentian, consisting mainly of moderately acidic eruptives, and Huronian. The term Laurentian is confined to areas of granite and granitoid gneiss corresponding to the Ottawa gneiss of eastern Canada and having eruptive relations to the Keewatin.

The Keeweenawan rocks of the various areas on the north shore of Lake Superior were studied, but no important conclusions were reached differing from those of Irving. One variety of conglomerate, made up chiefly of underlying Laurentian rocks, is common on the north shore, which apparently has not been found on the south shore.

COLEMAN,[275] in 1900, gives a general account of a visit to all the iron and copper regions of the Lake Superior country. For the ranges on the United States side of the boundary no facts are given not found in the published reports. On the Canadian side of the boundary the Michipicoten range, the iron formation near Dog River, and the siliceous iron ores of Batchawana Bay are described. In the Michipicoten range the Helen mine in particular is referred to. In general, the rocks, including the ore at this mine, have all the appearance of Lower Huronian or Keewatin rocks, as in the Vermilion district, and not those of the Upper Huronian or Animikie, as in the Mesaba.

Near Dog River are iron-formation rocks similar to those extending northeast from Michipicoten Bay. It is thought probable that the two may connect.

The occurrence and relations of iron-formation material northeast from Michipicoten Bay and near Dog River are indicated on a sketch map.

COLEMAN,[276] in 1900, as a result of an examination of the new Michipicoten iron district and the consideration of other iron-formation areas in Ontario, has collected facts which seem to throw some light on the relative ages of the different areas mapped as Huronian on the north shore. In the Michipicoten district iron-formation material, consisting of banded ferruginous sandstones, cherts, and jaspers, standing nearly vertical, extends from Little Gros Cap northeastward for 20 miles; then bending to the north and west, it takes a westerly direction for more than 30 miles. The width of the belt is but a few hundred yards.

Sandstones of the same peculiar type occur at Little Turtle Lake, east of Rainy Lake, and near Fort Frances, on Rainy River, as well as at the Scramble gold mine, near Rat Portage, on Lake of the Woods. Thin sections of these rocks show the same polygonal shapes of the grains of quartz, and more or less iron ore is associated with specimens from each locality. It is very probable, then, that the same horizon exists at points far to the west of Lake Superior.

Turning toward the east, specimens very like the jaspery varieties of the Michipicoten iron range are found interbedded with iron ores near Lakes Wahnapitae and Temagami, between Sudbury and Ottawa River.

At Batchawana Bay, at the southeast end of Lake Superior, a siliceous rock with narrow bands of magnetite occurs, which is probably the equivalent of the Michipicoten rock.

If, as seems probable, these jaspers are the equivalents of the western Huronian sandstones, there is a definite horizon traceable from point to point across the whole northern end of the province, a distance of more than 600 miles.

At a number of places over this area conglomerates containing jasper, ferruginous sandstone, or chert pebbles, probably derived from the source above described, are known. Beginning at the west, some of these conglomerates occur as follows: On Shoal Lake, east of Rainy Lake; west end of Schist Lake; near Mosher Bay, at the east end of Upper Manitou Lake; a mile east of Fort Frances on Rainy River; near Rat Portage; near the mouth of Dore River; in the Original Huronian area, north of Lake Huron, particularly the Thessalon area; on Lake Temiscaming.

It is assumed that the iron-formation material can not be other than Lower Huronian, and that the conglomerates must represent a basal horizon of the Upper Huronian. The break between the Upper and Lower Huronian thus represented is a most profound one, and affords a good basis for the correlation of the Huronian formations. It is further suggested that this great unconformity may be the same as that between the Upper and Lower Huronian formations on the south shore of Lake Superior and in Minnesota.

Van Hise and Clements,[277] in 1900, make observations on the region of the north shore of Lake Superior. They were together in the areas of Thunder, Black, and Nipigon bays. Lake Nipigon was examined by Clements and the north and east shore of Lake Superior east of Nipigon Bay by Van Hise.

At Port Arthur the Keewatin rocks are found to be the same as the typical Archean rocks of the Vermilion district of Minnesota—greenstones, green schists, and mashed porphyries. The iron-bearing phases associated with these have the same complex relations as in the Vermilion district, although the proportion of black jasper is greater than in the Vermilion district. This series can probably be connected to the west with the Mattawin iron formation and through this formation with that occurring north of the Saganaga granite of the Vermilion district.

About Thunder Bay at several places the basal conglomerate of the Keweenawan is in actual contact with the underlying Animikie and contains fragments of it, thus showing conclusively the unconformity between the Animikie and the Keweenawan. That the laccolithic sills of diabase which so characteristically intrude the Animikie slates of this area are of Keweenawan or later age is supported by the facts that the basal Keweenawan conglomerate contains no fragments of this diabase and that at various places the diabase is found cutting both the Animikie and the Keweenawan.

At Black Bay the Keweenawan sediments are interbedded with basic flows and contain pebbles of basic eruptives and acidic porphyries, showing that at this locality the volcanic outflows of Keweenawan time occurred before the deposition of the sediments.

At the mouth of Nipigon Bay are gabbro, amygdaloidal lava, and red rock, which are strongly believed to be a series correlative with the Beaver Bay group.

East of Nipigon Bay Van Hise finds a complex of spheroidal greenstones, green schists, gneisses, and granites, showing the usual intricate relations of the Archean. Also at intervals east as far as Schreiber are exposures of Animikie and Keweenawan, capped by columnar jointed diabase with the usual steep north faces and gentle dips toward the lake. In general there is a thin conglomerate at the base of the Animikie, although in places this is lacking.

From Steel River to Heron Bay is a greenstone and green schist complex, in all respects analogous to that of the Marquette district—mashed greenstones forming schists, banded slaty phases, greenstone tuffs, and conglomerates.

From south of Pic River nearly to Pukaskwa River Van Hise follows Logan and Irving in making all the area Laurentian in the sense of being Archean and including later eruptives. He can see no criteria for the separation into Laurentian and Huronian, as there is no sharp line separating the areas of greenstones and green schists and the massive granites.

Batchawana Bay is unique in showing four geological systems—(1) Archean granite gneiss schist, (2) Huronian graywacke, (3) Keweenawan amygdaloids, and (4) Cambrian sandstones. Batchawana Bay is probably structurally a minor syncline.

Clements finds about Lake Nipigon the following rocks: (1) Fairly massive greenstone, which very commonly shows well-developed ellipsoidal parting. With this are associated schistose phases. (2) Derived from the greenstones, and stratigraphically overlying them, is a series of sediments consisting of conglomerates, graywackes, and slates, the first two predominating. With these at one locality are bands of hematite and jasper, forming an iron-bearing formation. These divisions are closely related and, since they represent the Archean of the Vermilion district, are classed as Archean. As a whole they have a green color and are more or less schistose. (These are the rocks which Bell has designated green schists and classified as of Huronian age.) These rocks are cut through by numerous dikes of granite, which are offshoots of the massive granite that occurs in various areas. (3) At Vermilion Bay he finds a limited occurrence of slates, graywackes, and conglomerates which are well bedded and stand approximately on edge, with east-west strike. These sediments overlie and are younger than a greenstone which is adjacent to them. They contain fragments of hornblende schist and granite, and are not observed to be cut by granite. (4) The youngest rocks are of Keweenawan age. These cover a greater area than do all the other rocks of the region combined. They may be divided into sediments, basic igneous rocks (dolerites), and acidic igneous rocks. The sediments are sandstones and dolerites, and are best exposed on the northeast side of the lake. The basic igneous rocks have a greater development than any other single phase. They range from fine-grained aphanitic basalt to coarse gabbro, sometimes slightly amygdaloidal, and appear to intrude the sediments as sills. The acidic rocks range from quartz porphyry to fine-grained granite, and probably correspond to the "red rock" of the Keweenawan on the shore of Lake Superior.

Bain,[278] in 1901, describes the iron belt of Lake Nipigon, devoting his attention mainly to economic and petrographic features. The stratigraphic features are covered in the general report of Coleman summarized on a previous page.

Coleman,[279] in 1901, reports on the distribution and lithology of iron ranges northeast and east of Lake Superior. Only incidental reference to structural geology is made.

Coleman and Willmott,[280] in 1901 and 1902, describe and map the Michipicoten iron ranges. The rocks are classified as follows:

Archean	Laurentian	Gneisses and granites.
	Upper Huronian	Basic eruptives. Acidic eruptives. Dore conglomerate.
	Lower Huronian	Eleanor slates. Helen iron formation. Wawa tuffs. Gros Cap greenstones.

The Gros Cap greenstones are basic eruptives with ellipsoidal structure, corresponding in position and character to the Ely greenstones of the basement complex of the Vermilion district of Minnesota. They are in part basal to the other rocks of the district, but in part also they are interbedded with the rocks of the Helen iron formation. The Wawa tuffs are acidic schists having the composition of quartz porphyry or felsite, usually in the form of tuff, ash, or breccia, and sometimes show stratification, taken to indicate deposition by water.

Slates of distinctly sedimentary origin, occurring in thin bands near Eleanor Lake and called the Eleanor slates, are referred to the Lower Huronian. Their relations to the Helen iron formation are not known.

The Helen iron formation, 500 feet thick, comprises banded granular silica with more or less iron ore, black slate, siderite with varying amounts of silica, and gruenerite schist. All are found well developed at the Helen mine, and all but the gruenerite schist have been found in the Lake Eleanor iron range also, while granular silica and siderite occur in large quantities in every important part of the range, though small outcrops sometimes show the silica alone. All the rocks of the iron formation contain considerable amounts of iron pyrites. The grained silica and the granular silica is similar in certain respects to the jaspers and ferruginous cherts of the United States, and their origin is believed to be the same. They differ in being often soft, pulverulent, and brecciated. The black, graphitic slate, forming a thin sheet just under the iron range proper west of the Helen mine and at other points in the region, seems closely related to the granular silica, being composed of the same material with a large admixture of carbon, which smears the fingers.

Iron ore is mined in the Helen mine, and this mine is described in detail. The ore body is located at the east end of the deep Sayers Lake basin, partly above and partly below the old water level. The lake has now been drained, and the ores appear in a great amphitheater opening out to the west. The rocks immediately associated with the hematite are siliceous ore, ferruginous cherts, or grained silica rocks. These are mapped as immediately surrounding the iron ore and also as forming for the most part the north wall of the amphitheater. The east wall of the amphitheater is composed of iron carbonate which shows gradations into siliceous ore and into hematite ore. The south wall is composed of Wawa tuffs.

The ores are believed to have resulted from secondary alteration of an original iron formation consisting mainly of iron carbonate, grained silica, and limestone, in part interbedded with the Wawa tuffs, but mainly deposited above them. The iron formation and the tuffs were folded together, with the result that the tuffs were formed into a trough underlying the iron formation and the iron formation within this trough was folded and brecciated. Percolating waters then altered the iron carbonates. Probably the chief solvent of the carbonates was acidic ferric sulphate or sulphuric acid resulting from the oxidation of the iron pyrites, which are found in considerable quantity throughout the iron formation. The ore body has resulted directly from the alteration of iron carbonate, the oxidation of the iron sulphide having yielded but little ore. The oxidation of the iron took place where solutions of iron carbonate came into contact with waters bearing oxygen.

The principal areas of iron formation possibly bearing iron ore are at Gros Cap, Sayers and Boyer lakes, just east of the Helen mine, around Brooks Lake, south of Long Lake, just east of Goetz Lake, in Parks Lake, and between Parks and Kimball lakes.

The Upper Huronian rocks are represented principally by the Dore conglomerate, occurring typically at the mouth of Dore River and thence eastward beyond Michipicoten Harbor, and to a less extent in other parts of the district. This conglomerate is unconformably above the Lower Huronian rocks of the district. It contains pebbles of granite, felsite, conglomerate, granular silica of the iron formation, and breccia.

The Dore conglomerate is cut by acidic intrusives in dikes and bosses. These are the latest rocks of the region.

The Laurentian granites and gneisses have not been studied in detail in the Michipicoten district, but their associations with both Lower and Upper Huronian prove them to be post-Huronian eruptive masses.

Coleman,[281] in 1902, discusses the origin of the rock basins of Boyer and Sayers lakes of the Michipicoten district of Canada, the former containing the Helen iron-ore body. He holds the lake basins to have resulted from the solution of the iron-bearing rocks long before glacial time.

Coleman,[282] in 1902, describes nepheline and other syenites near Port Coldwell, Ontario, and calls attention to their widespread distribution in Ontario and the United States.

McInnes,[283] in 1902, gives a brief preliminary account of the nature and distribution of the Laurentian and Huronian rocks in the region southeast of Lac Seul.

Wilson,[284] in 1902, gives a brief preliminary account of the nature and distribution of the Laurentian, Huronian, and Cambrian rocks in the region west of Nipigon Lake and River. The Huronian is represented by a highly ferruginous quartzite occurring in a small area commencing near the southeast corner of Black Sturgeon Lake and extending southeast to the vicinity of Nonwatinose Lake. Animikie sediments and traps assigned to the Cambrian make up a large part of the area. Dolomite is conspicuous in this series.

Parks,[285] in 1902, gives a brief preliminary account of the area east of Nipigon Lake and River.

Coleman,[286] in 1902, gives results of an examination of the iron ranges of northwestern Ontario, principally the Mattawan, Atikokan, Steep Rock Lake, and other districts along the Canadian Northern Railway, the Slate Islands in Lake Superior, and near Dryden, on the Canadian Pacific. The description of the details of the districts contains but few references to general stratigraphy and correlation, but at the end a general classification of the iron ores of Canada is given. To the upper part of the Lower Huronian (Animikie of the United States Geological Survey) are referred the siliceous and sideritic iron ranges occurring in practically every iron-bearing area in Ontario, but being mined at only one place—the Helen mine, in the Michipicoten district. To the lower part of the Lower Huronian are referred the magnetite lenses in green schists of the Atikokan district and the titaniferous magnetite occurring as segregations in basic eruptives, especially gabbro. To the Grenville series, "probably Huronian," are referred the magnetite and hematite ores associated with bands of crystalline limestone and gneiss of eastern Ontario. To the Animikie or Lower Huronian (Upper Huronian of the United States Geological Survey) are referred impure siderite and hematite occurring in the neighborhood of Thunder Bay and also near Algoma. To the Pleistocene are referred the bog and lake ores and postglacial magnetic sands occurring widely in Ontario, especially in the eastern part.

MILLER,[287] in 1903, gives a résumé of the occurrences of iron ore in northern Ontario and incidentally discusses their geological relations.

PARKS,[288] in 1903, gives a brief preliminary account of the region lying northeast of Lake Nipigon. Laurentian, Huronian, and Animikie rocks are present.

McINNES,[289] in 1903, gives a brief preliminary account of the geology of the region on the northwest side of Lake Nipigon.

MILLER,[290] in 1903, describes bowlders of nepheline syenite near Sturgeon Lake, northwest of Lake Superior, indicating the occurrence of rocks of this character in the pre-Cambrian rocks farther north.

SMITH and assistants,[291] in 1904, map and describe the geology of the Animikie or Loon Lake iron-bearing district on the northwest shore of Lake Superior and the country westward to Current River. The rocks of the district comprise Keewatin green schists and mashed porphyries, Lower Huronian graywackes and greenstones intruded by granite, Upper Huronian or Animikie iron formation and black slate containing sills of igneous rocks, Keweenawan conglomerates and sandstones containing diabase sills, and greenstones and porphyrites of unknown age. The Keewatin and Lower Huronian rocks form the highlands back from the Lake Superior shore. The graywackes and schists of these series are much folded and fractured and have developed a nearly vertical cleavage with a general trend of N. 60°–65° E. The Upper Huronian and Keweenawan rocks rest upon the south slope of this complex and dip in general toward the lake at angles of 5° to 10°, with local variations beyond these limits. Their distribution is complicated by two and perhaps more normal faults striking about N. 70° E., probably intersected by another set trending a little east of north. The downthrow in each case is toward the north, with the result that the series is repeated and occupies a larger area than it otherwise would. Evidence of a pronounced unconformity between the Lower Huronian and the Keewatin was observed in a cut along the Canadian Pacific Railway 2 miles west of

Mackenzie station. The unconformity between the Upper Huronian and the Keewatin and Lower Huronian rocks is evidenced by the attitude of the beds and by conglomerates observed at many places. Conglomerates at the contact with the Lower Huronian graywackes are found in the explorations south of Loon Lake and in the area to the southwest, at the contact with the Keewatin in the vicinity of Current River, and at the contact with the granite about 2½ miles south of milepost 110 on the Canadian Pacific Railway. The unconformity between the Keweenawan and the Animikie is not clearly apparent in difference in dips, which are nearly the same, but the base of the Keweenawan, when followed for a considerable distance, may be found to rest successively upon the different members of the Upper Huronian series and upon the Lower Huronian series. Near Deception Lake, south of Loon Lake station, the discordance in structure may be seen within an area of a few yards. The contacts throughout are marked by conglomerates containing fragments of the underlying rocks, predominantly granite and iron formation.

Van Hise, Bell, Adams, Miller, Lane, Seaman, Smith, and Leith,[88] in 1904, visited the area about Loon Lake and Port Arthur. In the Loon Lake area the succession is as follows: The top series is the Keweenawan, here consisting of sandstone above and conglomerate below, with interbedded basic igneous flows or sills. Below the Keweenawan is the Animikie. The contact between the Keweenawan and the Animikie was seen at two places. At one of these there is an appearance of conformity, but at the other the eroded edges of the Animikie iron-bearing formation are traversed by the Keweenawan beds. At one contact the base of the Keweenawan rests on the Animikie slate interstratified with the iron formation, and at the other on one of the members of the iron-bearing formation. At both localities the conglomerate at the base of the Keweenawan bears detritus from the underlying series, including both the slate and the iron-bearing formations of the Animikie. The Animikie succession which was seen near Loon Lake includes two phases of the iron-bearing formation with an interstratified belt of slate. The Animikie here has in general rather flat dips, although locally they become somewhat steeper.

At one place near Loon Lake a test pit has been sunk to the bottom of the Animikie, and here at the base of the formation is a conglomerate bearing fragments of the next underlying series, a graywacke slate. This graywacke slate covers a large area, shows cleavage at a high angle, and is evidently an important formation in the district.

The party has no doubt that there is a considerable unconformity between the Keweenawan and the Animikie, and a very important unconformity between the Animikie and the graywacke slates.

VAN HISE, BELL, ADAMS, MILLER, HAYES, SEAMAN, and LEITH,[88] in 1904, visited the Rainy Lake district. At the east end of Shoal Lake the Coutchiching schists form the highest formation. These are a series of micaceous schists graduating downward into green hornblendic and chloritic schists, here mapped by Lawson as Keewatin, which pass into a conglomerate known as the Shoal Lake conglomerate. This conglomerate lies upon an area of green schists and granites known as the Bad Vermilion granites. It holds numerous large, well-rolled fragments of the underlying rocks and forms the base of the sedimentary series. It is certain that in this line of section the Coutchiching is stratigraphically higher than the chloritic schists and conglomerates mapped as Keewatin. On the south side of Rat Root Bay there is also a great conglomerate belt, the dominant fragments of which consist of green schist and greenstone, but which also contain much granite.

In the Lake of the Woods area the party (except Hayes) made one main section from Falcon Island to Rat Portage, with various traverses to the east and west of the line of section. The section was not altogether continuous, but a number of representatives of each formation mapped by Lawson were visited. Lawson's descriptions were found to be substantially correct. Belts of sedimentary slate of any considerable magnitude were not found. At one or two localities subordinate belts of slate which appeared to be ordinary sediment, and one narrow belt of black slate which is certainly sediment, were found. Many of the slaty phases of rocks seemed to be no more than the metamorphosed ellipsoidal greenstones and tuffs, but some of them may be felsite. However, it is not asserted that larger areas may not be sedimentary in the sense of being deposited under water. Aside from the belts mapped as slate, there are great areas of what Lawson calls agglomerate. These belts mapped as agglomerates seem to us to be largely tuff deposits, but also include extensive areas of ellipsoidal greenstone. At a number of places, associated and interstratified with the slaty phases, are narrow bands of ferruginous and siliceous dolomite. For the most part the bands are less than a foot in thickness, and no band was seen as wide as 3 feet, but the aggregate thickness of a number of bands at one locality would amount to several feet.

No structural breaks between the above-mentioned formations of the Lake of the Woods could be discovered. The various classes of materials—slates, agglomerate, and ellipsoidal greenstones—all seem to belong together. In short, these rocks on the Lake of the Woods seem to constitute one series which is very largely igneous or volcanic in origin, but does, as above mentioned, contain sediments. This series in the Lake of the Woods area is the one for which the term Keewatin was first proposed for the greenstone series, Lawson giving as one reason for proposing this name the statement that there is no evidence that these rocks are equivalent with the rocks of Lake Huron described by Logan and Murray as Huronian.

The ellipsoidal greenstone agglomerate slate series is cut in a most intricate way by granite and granitoid gneiss, which constitutes much of Falcon Island at the southern part of the Lake of the Woods and a great area north of the Lake of the Woods.

BELL (J. M.),[292] in 1905, makes a report upon the iron ranges of Michipicoten West, covering the northern and western extensions of the producing Michipicoten iron-range district, adjacent to Michipicoten Bay. The northern range lies between Magpie River and the western branch of Pucaswa River, being practically continuous with the old Michipicoten range. The western range, separated from the other by granite, lies between Otter Head and Bear River, on the Lake Superior shore, and extends but a short distance north of Lake Michi-Biju. Coleman and Willmott's report on the Michipicoten area in the vicinity of the Helen mine is followed closely. Their succession is:

Keweenawan	Basic eruptives.
Post-Huronian	Acidic eruptives.
Upper Huronian	Dore formation.
Unconformity.	
Lower Huronian	1. Helen iron formation. 2. Michipicoten schists, etc.

Under the recommendation of the joint geological committee, referred to in a footnote, the Lower Huronian schists and iron formation would be classed as Keewatin and the Dore formation of the Upper Huronian would be called Lower Huronian.

The Helen formation consists of sideritic and pyritous cherts, jaspers, amphibolitic schists, siderite, iron ores, quartzite, phyllites, and biotitic and epidotic schists, all undoubtedly sedimentary. The formation occupies a position generally close to the overlying Dore conglomerate, but sometimes great masses of green schists (Keewatin) intervene between it and the Dore formation. Pronounced faults in the iron formation may be seen in several parts of the northern and western Michipicoten ranges. The western range is less folded than the northern range. The origin and development of the different phases of the iron formation are thought by Bell to be those given by Van Hise for Lake Superior ores, and emphasis is laid on the similarity of conditions in the Michipicoten and Vermilion districts.

Glacial erosion seems to have removed the upper parts of the formations, and ore deposits should be looked for only in deep troughs, such as those at Iron Lake, Frances mine, Brotherton Hill, at the Leach Lake bands in the northern range, and in Laird's claims, Julia

River bands, David Katossin claims, and Lost Lake claims in the western range. No important ore deposits have yet been found.

Burwash,[293] in 1905, describes and maps the Keweenawan rocks making up the Michipicoten and adjacent islands. The succession and thickness are as follows:

Keeweenawan rocks of Michipicoten and adjacent islands.

		Feet
1. Felsite of islands off the south shore		1,000
2. Pitchstone bed		530
3. Quartzless porphyry of Quebec Harbor		695
4. Melaphyre porphyrites of Channel Lake		1,660
5. Quartz porphyries	1	355
	2	1,160
	3	1,493
6. Beds exposed at lake on road		1,575
7. Felsite		513
8. Diabase porphyrite		463
9. Beds underlying farm (3)		1,140
10. Several beds at mine		645
		11,229

The dips vary from 40° to 55° S. Keweenawan rocks are found on the mainland to the north. If these form a part of the continuous succession with the Keweenawan rocks of the island, there is here represented a minimum thickness of 34,860 feet of sediments, unless faulting is present. This corresponds with Irving's estimate of 35,000 feet for the Keweenawan series on Keweenaw Point.

Coleman,[294] in 1906, in discussing the report of the international geological committee on the Lake Superior region, holds that the Coutchiching series of the Lake of the Woods region was, in the main, lower than the Keewatin as held by Lawson, though the mica schists which overlie the basal conglomerate at Shoal Lake should be excluded from the Coutchiching series. He holds also that the term Laurentian should be retained in its old sense for acidic rocks intrusive into the Huronian. Further, the Keweenawan should go into the Huronian series if the Animikie is placed there. Huronian would then mean the same as Algonkian and the latter term should be dropped.

Silver,[295] in 1906, maps and describes the geology of the Animikie iron range from Port Arthur eastward 25 miles. His succession and structure are essentially the same as those previously worked out by Smith and Allen, with the exception that he classifies certain greenstones, called Keewatin by Smith, with the Lower Huronian, having failed to recognize an unconformable break between them.

Coleman,[296] in 1907, describes and maps the distribution of the iron ranges east of Lake Nipigon, Ontario, in the neighborhood of

Poplar Lodge and Sturgeon River, and tabulates the rocks of the region as follows:

Archean	Later eruptives—gabbro, diabase, etc.	
	Lower Huronian—conglomerate and probably slate and arkose.	
	Keewatin	Iron formation.
		Green and gray schists, sometimes sideritic.
		Greenstones and volcanics.

Many details of distribution are given.

MOORE,[297] in 1907, reports on the iron ranges around Lake Windegokan, east of Lake Nipigon, Ontario. The rocks of the district, classified in accordance with the recommendations of the international committee on pre-Cambrian nomenclature for the Lake Superior region, are as follows:

Pleistocene—drift and swamp.	
Keweenawan—basic eruptives.	
Lower Huronian—conglomerate.	
Keewatin	Arkose.
	Iron range.
	Carbonate schists.
	Green schists.

It is difficult to decide whether the different members of the Keewatin series are arranged in their proper order of succession, because most of the rocks are badly decomposed and the contacts are so poor and complicated that little can be learned from them. The Iron range fixes a definite geological horizon, and most of the green schists are older than that formation, but the case is not so clear with regard to the position occupied by the carbonate schists and arkoses. The former correspond closely in composition to the Wawa tuffs of the Michipicoten region, and we have placed them in the same relative position here.

The arkoses, which are widely distributed in the region, are the most troublesome of all the rocks to classify in their proper order. In older works they are commonly included in the Upper Huronian, and on account of the presence of some jasper fragments which were seen in one section one would suppose that they should be placed in the Huronian above the conglomerate. Another thing which would make it appear as if the arkoses were later than the conglomerate is the absence in many places of any sign of schistosity, which is so common in the other rocks. But in some parts the arkoses are rather schistose, and it may be that in others they resisted the forces which caused the schistosity and remained massive, just as portions of the greenstones have retained their original structure while others became schistose. Also the absence of any considerable quantity of jasper, or any definite relation to the conglomerate, which would fix the relative ages, and the presence in the region of arkoses which are distinctly associated with the green schists, make it seem wiser to place them in the Keewatin.

The conglomerate forms a fixed horizon separating the Keewatin and Lower Huronian. It contains pebbles of practically all the types of rock in the region, and some which are not now found there. The absence of arkose pebbles is significant, but these rocks seem to be rather local, and since the material for the conglomerate has probably been transported some distance this might account for the absence of these pebbles.

One finds no objection to placing the basic eruptive in the Keweenawan, since it is composed of a large sheet of olivine diabase cutting the other rocks of the region.

SECTION 5. LAKE SUPERIOR REGION (GENERAL).

SUMMARY OF LITERATURE.

Schoolcraft,[298] in 1821, makes various observations on the crystalline rocks. At Granite Point is found a bluff of granite which is traversed by irregular veins of greenstone trap. The sandstone laps upon the granite and fits into its irregular indentations in a manner that shows it to have assumed that position subsequently to the upheaving of the granite. Its horizontality is preserved even to the immediate point of contact. All the rock along the south shore of Lake Superior is either red or gray variegated sandstone, which appears to be referable to one formation. On passing by the Porcupine Mountains the red sandstone is visible along the shore in a position nearly vertical, dipping under the lake toward the north. Red sandstone in a vertical position is found at the mouth of Montreal River and for a few miles beyond it toward Chequamegon Bay. On St. Louis River, after passing red sand rock in a horizontal position, is found on the banks of the river a slate (argillite) in a vertical position traversed by greenstone and milky quartz. At the grand portage of the St. Louis the country is rough, consisting of slate in a vertical position. This continues for a long way and is succeeded by hornblende, which continues to the head of Grand Rapids.

Cunningham,[299] in 1845, Sanders,[300] in 1845, Campbell,[301] Sanders,[302] Gray,[303] in 1845, and Gray,[304] in 1846, give various detailed observations as to the mineral regions of Lake Superior, but little or nothing of structural interest.

Rogers,[305] in 1848, remarks that the south shore of Lake Superior is outlined by a series of east-west dikes.

Agassiz,[306] in 1850, describes the outlines of the shore of Lake Superior as largely due to six different sets of dikes of different mineralogical character, and each system running parallel to one of the main shore lines, although it would be a mistake to ascribe the form to any single geological event. Its position in the main is doubtless determined by a dislocation between the Primitive range north and the sedimentary deposit south. The rocks of the north shore of Lake Superior are extensively metamorphic. The New Red sandstone passes into porphyries, quartzite, granite, and gneiss, the metamorphism being more or less perfect, so that the stratification is still sometimes preserved or passes gradually into absolutely massive rocks.

Owen,[307] in 1851, mentions various metamorphic slates, quartzites, and other crystalline and trappean rocks as occurring on the south shore of Lake Superior. On the north shore, in Minnesota, between Fond du Lac and the British possessions there is a repetition in inverse order of the same formations, forming a synclinal trough with the red sandstone nearest the lake, while the slates, conglomerates, and associated traps are crossed in succession in proceeding into the interior, and these are followed by the metamorphic slates and granitic rocks.

Owen,[308] in 1852, discusses the age of the red sandstones of Lake Superior. The test of lithological character, if alone applied, favors the view that they are of the same age as the red sandstones of New Jersey and Nova Scotia. On St. Croix River, in Wisconsin, the white and buff quartzose sandstones belonging to the lowest Protozoic formation are succeeded by red sandstones similar to those of Lake Superior and, like them, are associated with coarse red conglomerates and trap. The same phenomena are seen at other points south of Lake Superior. It is, however, conceivable, as a result of the upthrust of igneous rocks, which sometimes break through the fossiliferous strata, entangling and partially indurating the fragments without altering or tilting adjacent beds, that tilted red sandstones dipping to the south may never rest conformably under the white and buff sandstones, but merely abut against them and not overlie them at all; but the natural and reasonable inference is that the white and buff sandstones do actually rest conformably upon the red sandstones in question.

Marcou,[309] in 1853, after having made a complete tour of Lake Superior, places the red sandstone and traps bearing copper as the New Red sandstone, and correlates it with the New Red sandstones of Nova Scotia, New Brunswick, Connecticut, New Jersey, Maryland, and Virginia.

Whitney,[310] in 1854, states that the basin of Lake Superior is a great synclinal trough caused by a depression of the sandstone, which appears to form its bed. The northern and eastern shores for much of their distances are faced by perpendicular cliffs, while the southern shore is comparatively low. The reason for this difference is that on the east and north the sandstone which originally existed there has been worn away and the more enduring granitic and trappean rocks only are left. The age and relations of the sandstones of Lake Superior to the trappean rocks and Azoic slates are again described as before.

SCHOOLCRAFT,[311] in 1855, states that the granite strata of the Thousand Isles reappear on the north shore of Lakes Huron and Superior, underlie the bed of the latter and are found on the rough coast between Chocolate River and Keweenaw, and cross the Mississippi near the Falls of St. Anthony. The Strait of St. Marys appears to be the ancient line of junction between the great calcareous and granitic series of rocks on the continent. The island of St. Joseph is chiefly Primitive rocks, and at its south end is largely loaded with granitic, porphyritic, and quartzitic bowlders. The north shore of the river, opposite the island, is entirely of the granite series, which continues to Gros Cap on Lake Superior. The red sand rock of Lake Superior is regarded as the Old Red sandstone. The formation of red jasper in white quartz exists on the southern foot of Sugar Island. In the granitic conglomerates are seen red feldspathic granite, black shining hornblende rock, white fatty quartz, and striped jasper, all held together firmly. Volcanic action appears to have thrown up the trap rocks of the Pic, of the Porcupine chain, of Isle Royal, and of the long peninsula of Keweenaw. The sandstone of the southeastern coast exhibits undulations of 8° or 10° at several places. Two instances of this are the Point des Grands Sables, beginning with the horizontal strata of the Pictured Rocks, and at Grand Island.

WHITNEY,[312] in 1856, describes the northeastern side of Lake Superior, from Gros Cap to Nipigon Bay, as consisting of rocks of the Azoic system. On the south shore of the lake, and along the northwest shore as far as the northeastern extremity of Nipigon Bay, are found the shales, sandstones, conglomerates, and trappean rocks of the Potsdam system, except at Thunder Bay and Carp River, where the Azoic appears. The south side of the Azoic on the north side of the lake runs from Kakabikka Falls on the Kaministiquia in an almost straight line southwest, keeping a few miles from the lake. Thunder Cape consists of thinly bedded slates for 800 feet of its thickness, above which is a sheet of trappean rock 200 or 300 feet thick.

WHITNEY,[313] in 1856, maintains that the iron ores of Lake Superior, Scandinavia, Missouri, and northern New York form a class by themselves belonging to the Azoic age, and that they have been poured out like other igneous rocks from the interior in a molten or plastic state. Besides the purest ores are others interlaminated with bands of quartz which are distinctly bedded and probably of sedimentary origin. The iron ore in these may have been introduced either by sublimation during the deposition of the siliceous particles or by precipitation from a ferriferous solution at the time of formation of the stratified rocks.

WHITNEY,[314] in 1857, again maintains the Potsdam age of the sandstones of the Cupriferous series. Underlying this series unconformably on the south shore is the Azoic series, which is identical in character with the rocks of Thunder and Black bays. The rocks on the north shore of Lake Huron and in the north and east of Canada are identical in position and lithological character with the Azoic system.

WHITTLESEY,[315] in 1876, finds nowhere on the American side of the boundary, except at Vermilion Lake, rocks which are like the Laurentian of Canada. The great masses of granite and syenite around which the Huronian is formed do not resemble the Laurentian of the Canadian geologists. Between the Canadian and American Huronian there is a very close resemblance. The conclusion of Foster and Whitney that the traps of Lake Superior are of Potsdam age is adopted. The Bohemian range resembles more nearly the Huronian than it does the trap series. In this range are bands of friction conglomerates with the evidences of metamorphic sandstone, passing into jasper, vesicular trap, and breccia. A friction conglomerate also occurs at Aminicon, Douglas County, Wis.

PUMPELLY, in 1878, describes Lake Superior as divided into two basins by Keweenaw Point. See summary in Chapter III, section 1, Michigan, page 128.

IRVING,[316] in 1883, gives a systematic account of the Copper-bearing rocks of Lake Superior. From this group is excluded the so-called lower group of Logan, the Animikie group of Hunt, and also the horizontal sandstones known as the Eastern and Western sandstones; although it includes the dolomitic sandstones with accompanying crystalline rocks between Black and Thunder bays, and occupies the valley of Black Sturgeon and Nipigon rivers, as well as Lake Nipigon. The Keweenaw or Copper-bearing series then includes the succession of interbedded traps, amygdaloids, felsitic porphyries, porphyry conglomerates, and sandstones, and the conformable overlying sandstone typically developed in the region of Keweenaw Point and Portage Lake. These rocks have their most widespread extent about the west half of Lake Superior, but also occur in the eastern part of the lake. The entire geographical extent in the immediate basin of Lake Superior is about 41,000 square miles.

The eruptive rocks include basic, intermediate, and acidic kinds, but there is no such chronological relation between these three kinds as is found to be the rule in Tertiary and post-Tertiary times. In the Palisades of the Minnesota coast quartz porphyries are found both overlain and underlain by basic rocks, with abundant evidence that the porphyry is a surface flow. The same phenomena are seen at other places. Acidic flows are superimposed upon basic flows, flows of intermediate acidity immediately overlie acidic flows, flows of intermediate acidity overlie porphyritic conglomerates, flows of intermediate acidity are superimposed upon basic flows, basic rocks are intersected by acidic rocks, basic flows overlie acidic rocks, basic flows overlie those of intermediate acidity, and acidic rocks are intersected by basic rocks. There is a complete absence from the series of anything like volcanic ash. The detrital rocks of the series are composed of fragments broken for the most part from the acidic rocks of the series—that is, such material as porphyry, both nonquartziferous and quartziferous, felsite, augite syenite, granitell, and granite; but there are also often found pebbles of the basic rocks, and in some cases particles of gneiss and granite from the underlying series. This is thought to be due to the fact that such viscous material would solidify into more or less bulky, erect masses of relatively small area, and thus be most favorably situated for degradation. Between the several kinds of original rocks there are no sharp lines, but a continuous series of kinds from the most basic to the most acidic.

The lithology of the different members of the series is given in detail. The basic original rocks include granular, porphyritic, and glassy kinds, the most abundant of which are gabbro, diabase, melaphyre, and porphyrite. The acidic original rocks include quartzless porphyry, quartziferous porphyry, and felsite, augite syenite, granite porphyry, and granite. Here are included the so-called "jaspers," which have been regarded by many as metamorphosed sedimentary rocks. The basic crystalline rocks make up the greater part of the thickness of the series, the beds varying from a few feet to several hundred feet in thickness. Each of these beds often has a twofold division, an upper amygdaloidal portion, and a lower compact portion, which, however, grade into each other. The amygdaloids not infrequently resemble beds of sedimentary origin, but they never show any trace of fragmental character, and the stratiform condition is seen to be due to a succession of thin flows and two fluidal structures. Laterally the beds are not of indefinite extent, and are far less extensive than sedimentary beds of the same thickness. It is generally, however, difficult to prove the continuity or noncontinuity of a single flow over a great distance, but on the Minnesota shore individual layers were traced with certainty for 10 or 15 miles, while other beds almost certainly have an extent of nearly 30 miles, and groups of layers of allied characters are recognizable over much longer stretches. The more massive, thicker beds generally occur in the lower part of the series. Numerous dikes cut the basic rocks. These are generally small, commonly not more than 10 feet in width, but in the immediately underlying series on the north shore, the Lower Copper-bearing or Animikie group, are dikes of great magnitude. Of the original acidic rocks true granite has been observed only in the Bad River region of Wisconsin, intersecting the coarse gabbro at the base of the series. Quartz porphyry and allied acidic rocks have a widespread occurrence, two of the largest masses being the Palisades of Minnesota and the core of the Porcupine Mountains of Michigan. The detrital members have often a great extent. The outer conglomerate of Keweenaw Point, for instance, is traced from the eastern extremity of the point to Bad River in Wisconsin, a distance of at least 170 miles, although its thickness in this distance varies from less than 100 to as much as 4,000 feet. Thinner conglomerates have been traced for as great a distance as 50 miles.

The Keweenaw series is stratigraphically separated into two grand divisions—an upper member, made wholly of detrital material, for the most part red sandstones and shale; and a lower division, made chiefly of a succession of flows of basic rocks, but including layers of conglomerate and sandstone nearly to the base, and also original acidic rocks. The line of separation between the two divisions is somewhat arbitrary, for the sandstone gradually increases in quantity upward, but above the highest known eruptive member is a maximum thickness of 15,000 feet of detrital material. The chief characteristics of the lower division are: First, coarse-grained basic rocks in very heavy beds are much more common at lower horizons; second, amygdaloidal texture is more frequent and highly developed at high horizons, this being more characteristic of the thinner beds; third, the gabbros are more often found at lower horizons, while the ordinary diabases and melaphyres affect higher horizons; fourth, the acidic rocks are found especially in low horizons, rarely reaching above the middle of the lower division; and, fifth, the detrital beds, although seen all the way to the base, are rare in the lower third of the series and increase in thickness and frequency toward the top. The coarse gabbros of Bad River, at the base of the series, present the appearance of unconformity. Lying immediately upon the Huronian slates, they taper out rapidly at both ends and seem to lie right in the course of the diabase belts to the east and the west. This coarse gabbro must have stood up to a great height and the later flows terminated against it until they had accumulated sufficiently to overflow its upper surface, but possibly they represent the slowly solidified and subsequently denuded reservoirs from which the later flows were in part derived. The great extent of coarse gabbros of Minnesota seems to sustain somewhat the same relations to the more regularly bedded portions of the series. Because of these relations the question arose whether these gabbros do not belong with the Huronian, but they appear to cut across the Huronian at a small angle and thus to be unconformable with this series; hence, because of the relationship lithologically and because sudden breaks in eruptive series have not the same significance as in sedimentary series, they are placed as the earliest of the Keweenawan flows. The thickness of the lower division is placed in round numbers at 25,000 to 30,000 feet, while at Montreal River its apparent thickness is 33,000 to 35,000 feet, but a part of this may be due to the westward continuation of the Keweenaw fault.

Detailed descriptions are given of the rocks of Keweenaw Point, of the region between Portage Lake and Ontonagon River, of the South range, of the region between Ontonagon River and Numakagon Lake, including the Porcupine Mountains, of northwestern Wisconsin and the adjoining part of Minnesota, of the Minnesota coast, of Isle Royal and Nipigon Bay, and of Michipicoten Island and the east coast of Lake Superior. Silver Mountain, belonging to the South range, is composed of diabase, dipping at an angle of 30°, and appears to be surrounded by horizontal sandstone. On the west branch of the Ontonagon are found cliffs of horizontal sandstone almost in proximity with ferruginous slate supposed to belong to the Huronian, and but a short distance from diabases regarded as Keweenawan. The isolated position of the South range is regarded as due to a fault, as there is no evidence whatever of a fold, and to regard this part of the series as a continuous conformable succession with the Keweenawan rocks to the north would give the series an incredible thickness. The Porcupine Mountains are found to be due to a subordinate fold in the series, the core being a quartz porphyry.

All the known facts with reference to the relations of the horizontal sandstone to the Copper-bearing rocks of northwestern Wisconsin and the adjoining parts of Minnesota are recapitulated. The unconformity between the fossiliferous Cambrian of the St. Croix Valley and the bedded melaphyre and amygdaloids described by Sweet, Strong, and Chamberlin is indisputable, and the latter rocks are identical in nature and in structure with the similar rocks of Keweenaw Point and have been shown to be in actual continuity with them. At Snake and Kettle rivers the diabase and diabase amygdaloids with interbedded porphyry conglomerates are in all respects like those of Keweenaw Point, and here, as shown by Chamberlin and McKinlay, the horizontal Cambrian sandstone overlies these beds unconformably. Sweet's examination of Kettle and St. Croix rivers shows that here are cupriferous rocks which are identical with those of Keweenaw Point, upon which the red sandstone of Lake Superior west of the Montreal reposes unconformably, at Black River, Copper Creek, Aminicon River, and Middle River. The disturbances of the overlying sandstone described by Sweet are due in part to the irregularities of an unconformable contact and to the pressure of the deep-seated Keweenaw rocks against the more shallow sandstone, but also in large measure to a faulting that has taken place along the contact line. The phenomena, if not explained as above, may be regarded as due to the intrusion of disturbing masses or dikes, as suggested by Whittlesey and Norwood, or the sandstone may be supposed to belong to the upper division of the Keweenaw series let down by a great fault. The first of these suppositions is forbidden by the bedded structure of the rocks, and the second is shown by the general structural features of Lake Superior to be a physical impossibility.

The amygdaloidal and porphyritic rocks, and the granite, granitic porphyry, and felsite of the Duluth gabbros and the Minnesota coast, are found in every case to be original eruptive rocks having all the evidences in their structure of this origin and none whatever of being metamorphosed shales and sandstones resulting from the red sandstones of Fond du Lac, as supposed by N. H. Winchell.

It is concluded that the Eastern sandstone along the south face of Keweenaw range is both a fault cliff and a shore cliff against which the newer sandstone was laid down, but not until after a large erosion, and that faulting again took place during or after the deposition of the sandstone; that this original faulting is demanded along this line by the relations of the Keweenaw and South ranges, without which the Keweenaw rocks would have an enormous thickness.

The relations of the Eastern sandstone and Keweenawan traps at Bete Grise Bay, along Hungarian River, and in Douglass Houghton ravine, are described and sections are given showing the sandstone to rest unconformably upon the eruptives. At the Torch Lake quarry the Eastern sandstone is found horizontally disposed in heavy layers, containing no fragments of porphyry such as are distinctive of the Keweenawan sandstones. No evidence of a northwesterly dip described by Wadsworth was here found. The sandstone adjacent to the trap is of the ordinary quartzose character. It is remarked that Wadsworth's statement that the feldspathic constituents have been leached from it, thus accounting for its differences from the Keweenawan sandstone, is a pure supposition. Farther west, on and near Ontonagon River, as at Bete Grise Bay, near the contact, the sandstone dips away from the northward-dipping Keweenawan diabases at a rather high angle, which rapidly flattens as distance from the contact increases. Finally, along the north face of the South range eastward from Lake Agogebic, the sandstone is not infrequently met in a flat-lying position, and at one place lies directly across the course of the Keweenawan belt.

As to the age of the Eastern sandstone, it is regarded as demonstrated that it is older than the Trenton; hence its Triassic age is not discussed. The Western sandstone is regarded as the equivalent of the Eastern sandstone, although they are not found connected, nor is the Western sandstone at any point connected with the Mississippi

Valley Cambrian sandstone. It has, however, already been shown that the Keweenawan rocks lie unconformably under the Cambrian sandstone of the Mississippi Valley in western Wisconsin.

The Animikie series in the Thunder Bay district is of great thickness, probably upward of 10,000 feet, comprising quartzites, quartz slates, clay slates, magnetitic quartzites, sandstones, thin limestone beds, and beds of cherty and jaspery material. With these are associated in great volume, both in interbedded and in intersecting masses, coarse gabbro and fine-grained diabase like those well known in the Keweenaw series. A broad examination of the region shows that there is little ground for the belief in one crowning overflow. The Animikie series is lithologically like the Penokee range in Wisconsin; both series bear the same relations to the newer Keweenawan rocks and the older gneisses, and the two groups are regarded as the same.

The Animikie rocks are also the equivalent of, if not actually continuous with, the Mesabi iron range running to Pokegama Falls and the slates of St. Louis River, although these latter are affected by slaty cleavage.

The Original Huronian of Logan is compared with the Animikie slates of Thunder Bay and the two are regarded as equivalent. The Marquette and the Menominee Huronian, with minor exceptions due perhaps to metasomatic changes, are lithologically like the Animikie and Penokee series, and are also regarded as belonging to the same horizon. The Original Huronian, the Animikie slates, the Penokee iron rocks, and the iron-bearing rocks of Marquette and Menominee appear, then, to belong together and hence may properly be called Huronian. The Huronian schists in each of these areas are limited by granite and gneiss. There are, however, considerable areas of crystalline schists the relations of which are doubtful, and it is suspected that in several of the iron regions there are two distinct kinds of schists—those belonging to the Huronian, and a schistose greenish phase belonging with an older series. It is also possible that a portion of the granites are eruptive and relatively new, while others, and especially those connected with the gneisses, may be of some sort of metamorphic origin not understood. The iron-bearing schists of Vermilion Lake are, however, so like the Huronian that they are regarded as a folded continuation of the Animikie beds.

That the Animikie Huronian is beneath the Keweenawan rocks is shown by the fact that the Keweenawan beds along the Minnesota coast are passed in descending order until the Animikie slates are reached at Grand Portage Bay, but there is not a direct downward continuation of the Keweenawan into the Animikie, for between the two there has been an intervening period of erosion. This is shown by the fact that at Grand Portage Bay, where the two formations come together, the underlying slates suddenly rise entirely across the horizon of 600 or 700 feet of the Keweenawan sandstone. Also in northeastern Minnesota and in the Penokee district the overlying Keweenawan is now in contact with one member of the underlying series and now with another. Further, in the Keweenawan sandstones of Thunder Bay are found chert and jasper pebbles from the Animikie, while in the Wisconsin Keweenawan are quartzite pebbles apparently from the underlying Huronian. More abundant than these in the Keweenawan conglomerates are pebbles of older gneiss and granite. Lithologically the Keweenawan rocks are also unlike the Huronian. The bedded and sedimentary series of the two groups are in strong contrast. The shales and sandstones of the Keweenawan have nothing in common with the quartz slates and quartz schists of the Huronian. Also in the Huronian there is nothing like the acidic eruptives of the Keweenawan. They have the common feature only of basic eruptive rocks, and of these in the Huronian there are no amygdaloidal or vesicular layers. A further difference between the Huronian and the Keweenawan is in the degree of metamorphism. The Keweenawan sediments are unaltered, while the Huronian sediments are metamorphic. Whether this metamorphism took place before or during the period of Keweenawan eruptions and deposition is uncertain.

That the closely plicated Huronian rocks were folded before Keweenawan time is indicated by the fact that the troughs of Huronian schists adjacent to Lake Nipigon lie directly athwart the flat-lying Keweenawan beds. If these schists are truly Huronian and equivalent to the unfolded rocks, as supposed by Bell, there can be no doubt of the existence of a genuine unconformity between the two systems. The Keweenawan syncline forming the bed of Lake Superior is found to comprise the whole basin, as well as a considerable area in northern Wisconsin and Minnesota. Not only the form of the lake as a whole, but its chief bays are due to subordinate folding or faulting of the Keweenawan series. In the great synclinal movement the underlying Huronian has partaken.

Chamberlin,[317] in 1883, gives a summary of the arguments for regarding the copper-bearing series of Lake Superior as pre-Potsdam: (1) The general stratigraphical relations, the weakest argument of all, indicate this. The Potsdam sandstone throughout the entire basin of Lake Superior is always horizontal, or nearly so, while the Keweenawan series at many points immediately adjacent have suffered extensive disturbance. (2) The difference in thickness is enormous; the Potsdam is rarely 1,000 feet thick, while the Keweenawan series has, in addition to a vast thickness of interstratified eruptives and detrital rocks, an upper portion free from igneous matter 15,000 feet in thickness. (3) The sandstones of the Keweenawan series are largely composed of silicates, while the Potsdam sandstone is mainly quartzose. (4) At numerous points the Potsdam is found to rest against or upon the upturned edges of the Keweenawan series unconformably. Strong has found fifty-five places on the St. Croix where the unconformable contact occurs. In Douglas County are four sections in which the Potsdam sandstones become conglomeratic, bearing material from the copper-bearing series, but here the contacts are complicated by subsequent disturbances. There are several other districts, such as upper St. Croix River, Snake and Kettle rivers in Minnesota, and the vicinity of Lake Agogebic in Michigan, where the quartzose Potsdam sandstone is in a horizontal position and near the upturned igneous and detrital rocks of the Keweenaw series. (5) The foregoing facts are all consistent with one another. (6) The view is dynamically simple, whereas any other explanation implies an extraordinary amount of local faulting and disturbance. (7) In the Grand Canyon of the Colorado is a series of rocks remarkably similar to the Keweenawan, which lie directly and unconformably below the Cambrian.

Irving and Van Hise,[318] in 1884, describe quartzites of many localities belonging to the rock series referred to the Huronian in the Northwest, and find that their supposed metamorphism is due to the deposition of interstitial silica, which has for the most part coordinated itself with the original grains, the forms of the latter being as perfect as at the time of deposition. The list of rocks given includes those from the Original Huronian, from the various iron-bearing regions of Michigan and Wisconsin, from the Baraboo and Chippewa quartzites, from the Minnesota, Iowa, and Dakota quartzites, and from other localities.

Irving,[319] in 1885, discusses the divisibility of the Archean in the Northwest. The relations of the Penokee-Gogebic series to the overlying Keweenawan and to the underlying complex are first discussed. The area south of the Penokee-Gogebic series is found to consist of crystalline hornblendic, chloritic, and micaceous schists, which locally show unmistakable evidence of fragmental origin, but which as a whole are intensely metamorphosed. The granites, however, are considered as of eruptive origin, as they intersect intricately the associated schists at their contacts with them, but the granite is never found to cut the overlying slates. Above this granite gneiss schist area is, first, a belt of slate 500 feet thick, over this a belt of iron-bearing rocks of various kinds, and above this quartzites and slates, all having a dip to the north and extending for many miles east and west. None of these rocks are metamorphic.

North of this succession of layers, the Penokee series, is the Keweenawan series, which appears at first to be conformable, but a closer inspection shows that it is now in contact with one member of the underlying series and now with another, even lying against the lowest member of the Penokee series. These relations are taken to imply that between the Keweenawan and Penokee series there was a long period of erosion. There is also an unconformity between the granite gneiss schist complex and the Penokee-Gogebic series. This is shown in the manner in which the regularly succeeding belts of the iron series traverse the courses of the lower; in the strong contrast between the two series in degree of crystallization, the lower series being nearly completely crystalline, while the higher is little altered; in the highly folded and contorted condition of the lower series as contrasted with the unfolded condition of the higher; in the contrast between the contacts of the granite with the lower schists and with the higher slates, the former being invaded by it in an intricate manner, the latter never; in the discordant lamination of the two sets of rocks when in contact or close proximity; and in the occurrence in the upper series, not only at horizons above the base, but also at points on the contact line, of abundant detrital material from the lower series.

In the Marquette district is found a slaty iron-bearing series which, by common consent, is regarded as the equivalent of the Penokee-Gogebic series; but the two have one point of contrast—the Marquette is highly folded. Here intervenes between the iron-bearing slates and the granites and gneisses a set of greenish hornblendic rocks, called by Rominger a dioritic group, which at their contact with the bounding granite are penetrated by them in the most intricate manner, so that one can not resist the conclusion that the granite is the more recently formed rock. These green schists are regarded as the equivalent of those cut by granite in the Penokee-Gogebic district. On this view the slate series of the Marquette district, consisting in the main of little altered rocks, was built up on a basement composed of granite and gneiss and greenish schist, and subsequently pushed into troughlike forms. In support of this view is cited the failure of the granite to penetrate the slates and quartzites associated with the iron, and the occurrence in the higher series of fragments from the lower, recomposed rocks at points where the quartzites come into contact with the basement rocks.

The Archean in these regions is then divisible unless the upper series are called Cambrian, for which there will be no ground until fossils have been discovered in them. These upper series are compared with the Huronian of Lake Huron, and are found to be lithologically like them, and to bear the same relations to the underlying rocks, and to them the term Huronian is applied, while the underlying complex is regarded as Laurentian.

Irving,[320] in 1885, gives a preliminary account of an investigation of the Archean formations of the Northwestern States. The problems to be solved are discussed. An examination of the Original

Huronian area of Murray and Logan shows that it is a series of rocks which is bent into gentle folds, and which is composed for the most part, excluding eruptive material, of quartzites and graywackes, with a subordinate proportion of limestone and chert. The rocks as a whole are very little altered and resemble more the fossiliferous formations than the crystalline schists.

The Marquette and Menominee iron-bearing series are highly folded and the metasomatic changes which the crystalline members of the series have undergone are often extreme. Excluding the greenish schists of the lower part of the series, which may belong to an older formation, the rocks are mainly fragmental slates and quartzites, including a large proportion of basic eruptives, and also iron ores, limestones, etc., the whole having a distinctly Huronian aspect. The various greenstone layers of Brooks's scheme are regarded as eruptive, either contemporaneous or subsequent, as are also many of the greenish schists which by gradation pass into the massive greenstones. The iron ore and jasper are regarded as of sedimentary origin, being remarkably like similar material in the Penokee-Gogebic and Vermilion formations, where there can be no doubt of their water-deposited character. In the Marquette district, as well as in the Vermilion Lake district in Minnesota, are conglomerates overlying the iron belt which sometimes contain fragments of the underlying formation several feet in length. These fragments prove the existence of the jaspery and chalcedonic material in its present condition before the formation of the overlying quartzite.

The Penokee-Gogebic iron belt is regarded as continuous with the Huronian of the Marquette district. The slate belt of St. Louis and Mississippi rivers is undoubtedly the equivalent of the Animikie series and of the Huronian. Equivalent with those are also the quartzites of Chippewa and Barron counties, the ferruginous schists of Black River, the Baraboo quartzites, and the quartzite series of southern Minnesota and southeastern Dakota.

At New Ulm and Redstone in Minnesota the quartzites and conglomerates plainly overlie the gneiss unconformably. The thickness of this formation here exposed is probably about 5,000 or 6,000 feet, a continuous section being found by Merriam at Sioux Falls, S. Dak., having a thickness of not less than 3,000 to 4,000 feet. The tilted position of these quartzites, their great thickness and their lithological contrast with the Potsdam sandstone make it evident that between these series and the overlying Potsdam sandstone is a great unconformity.

In the Animikie series is a strongly marked continuous horizon of cherty and jaspery magnetitic schists and quartzites. The series as a whole is quite flat lying, although having subordinate irregularities. The series having ferruginous schists north and west of Lake

Superior is regarded in part as having been once continuous with the Animikie series and is now separated merely because of erosion on the crowns of the folds, the close folding of the Vermilion schists being produced concomitantly with the broad simple trough of Lake Superior. In support of this position is the fact that the great conglomerate of Ogishki Manissi, with the alternating quartzites and slates of Knife Lake, is strikingly like the Huronian rocks. Moreover, in the vicinity of Agamok Lake the Animikie quartzites appear gradually to take on a folded condition.

In these various Huronian areas quartzites, graywackes, and clay slates, with intermediate phases, make up the most of the clastic series. As has been seen, these are rocks which have been indurated by metasomatic changes, and it follows that the bulk of the rocks which form the Huronian do not properly fall under the head of metamorphic rocks. The various augitic and hornblendic greenstones, peridotites, and felsitic porphyries are regarded as eruptives, while many of the schists are modified rocks of the same character. The cherty and jaspery rocks are supposed to be some sort of original chemical sediment, certainly not the result of metamorphism of sedimentary material. The limestones are in no essential respect different from many met with in the formations of later date.

Irving,[321] in 1886, discusses the origin of the ferruginous schists and iron ores of the Lake Superior region. An examination of the Animikie, Penokee, Marquette, Menominee, and Vermilion districts reveals the fact that in all of them is found abundant carbonate of iron, which oftentimes grades into the other forms of the iron-bearing formation. The silica of the jasper, actinolite, magnetite schists, and other forms of the iron belt never shows any evidence of fragmental texture, so easily discovered in the case of the ordinary quartzites and graywackes, and is therefore of chemical origin. Associated with the iron-bearing beds is often a considerable quantity of carbonaceous or graphitic schists. It is concluded: (1) That the original form of the iron-bearing beds of the Lake Superior region was that of a series of thinly bedded carbonates, interstratified with carbonaceous shaly layers in places, which were more or less highly ferriferous. (2) That by a process of silicification these carbonate-bearing layers were transformed into the various kinds of ferruginous rocks now met with. (3) That the iron thus removed from the rock at the time of silicification passed into solution in the percolating waters, was redeposited in various places, and thus formed the ore bodies and bands of pure oxide of iron. (4) That in other places, instead of leaching out, the iron has united with the silicifying waters to form the silicates now found, such as actinolite. (5) That some of the silicifying process went on before the folding, but some afterward, and to the latter period belong probably the larger bodies of crystalline ore.

IRVING,[322] in 1887, discusses the separability of a Huronian group from an underlying series. The character of the Original Huronian area is again fully discussed. When two series of rocks are in contact, one of which is crystalline in character and the other unquestionably of sedimentary origin, there is presumptive evidence of a discordance between them, as, whatever the origin of the crystalline schists, their present condition indicates the action of long-continued and deep-seated processes of alteration and profound erosion before the deposition upon them of the overlying detritals. In the Original Huronian area there is not only this distinction in its most marked form, but the actual contact between this series and the Archean complex is found near the mouth of Thessalon River, the upper series having at its base a basal conglomerate, the fragments of which are plainly derived from the foliated crystalline underlying series. Allied phenomena are also seen on the Canadian Pacific Railway between Algoma Mills and Sudbury. It is concluded that the Huronian has a group value, because it is essentially noncrystalline, because it is truly clastic and sedimentary, and because it has an immense volume. There is reason to believe that the area which stretches from the north shore of Lake Huron to Mississippi River, including the basin of Lake Superior, is one geological basin.

In the Marquette district the contradictory conclusions reached by older writers are regarded as due to the fact that the stratiform rocks themselves are made up of two entirely distinct sets—an older series of intensely altered and crumpled crystalline schists, in the main of greenish color, which are intricately invaded by the granite, and a newer, little altered, mainly fragmental series whose contacts with the granites and the schists of the older basement are such as to render an intervening structural break evident. The peculiar granitoid quartzites which Rominger regards as having been produced by the metamorphosed action of granite are plainly detrital derivatives from the granite, and often run into coarse bowlder conglomerates, particular occurrences of which are described. Here, as north of Lake Huron, proofs of distinctness of the newer series are a general lithological contrast between the two; visible discordances; the penetration of the lower strata of the lower series by granite veins which fail to penetrate the higher detrital rocks, but yield fragments to them; the development of true basal conglomerates at the contacts of the two series; and the fact that the higher detrital rocks are in contact with different members of the lower series. The most abundant of the upper series of detrital rocks are quartzites, but there are also present clay slates, shales, mica schists, and various calcareous and dolomitic rocks, with jasper and ferruginous schists and iron ores which are regarded as chemical sediments.

Southward from Marquette are great areas underlain by the granites, gneisses, and schists of the older formation, but before Menominee River is reached at least four distinct belts, occupied by the newer iron-bearing series, are crossed. These belts of newer rocks are more closely folded than in the Marquette district, but the relations between the newer and the older series are identical with those in that district.

In the Penokee district of northern Wisconsin and Michigan the iron-bearing series is highly tilted but unfolded, and the relations are therefore particularly plain. Here the lower of the two unconformities is established by (1) the fact that the iron-bearing series traverses lithologically distinct areas of the older or basement formation; (2) the intersection of the older schistose rocks by granite which never cut the higher series; (3) the occurrence in the higher series of basal conglomerates, fragments of which are from the underlying gneiss, granite, and schist; and (4) the lithological contrast of the two sets of rocks, the lower being completely crystalline, folded, and foliated, while the upper is but little altered and regularly bedded. The upper unconformity is shown by the manner in which the flows of the Keweenaw series are found in contact with all members of the iron series at different places along the contact line.

The Animikie series is gently tilted, and rests in palpable unconformity upon a folded series of schists, granites, and gneisses. Above it is the Keweenaw series, which bears the same relations to the underlying rocks as they do to the Penokee series.

North of the Animikie beds are schistose iron-bearing rocks, which extend from Vermilion Lake to the vicinity of Knife and Saganaga lakes. These are flanked by gneisses and granites, and on account of their lithological similarity to the Animikie rocks are taken to be their folded equivalent. While there is not here the same palpable unconformity as in the other regions discussed, it is believed that there are two groups of rocks, the apparent conformity being due to the intense folding.

There is, then, a graded series in the structural relations of the older and newer rocks, from the Animikie, which lie upon the older formations with a slight inclination, through the Penokee, which is unfolded, although deeply inclined; the typical Huronian, which is gently folded without schistose structure; the Marquette, which is crumpled between walls of older schists; the Menominee, in which the folding is so close that the discordances are no longer distinct; to the rocks of Vermilion Lake, where extreme pressure has produced a general community of inclination between the two groups of rocks. In all these regions there is a great basement complex of crystalline schists, gneisses, and granites, above which, separated by a great structural hiatus, is the Huronian group, mainly of detrital rocks, which is followed in turn, after a severe structural break, by the Keweenaw group, upon the eroded edges of which rests the Potsdam or Upper Cambrian sandstone. For the combination of clastic series above the basement complex and below the Potsdam sandstone the system name Agnotozoic is proposed.

Winchell (N. H.),[323] in 1888, maintains that there is a great Primordial quartzite extending from New England through Canada, Wisconsin, and Minnesota to the Black Hills of Dakota. It includes the Taconic quartzite of Emmons, that of Sauk and Barron counties in Wisconsin, the Sioux quartzite of Dakota, the quartzites of Minnesota, and those of the Black Hills of Dakota. At the exhibition in New Orleans in 1884 was seen a block of the Potsdam sandstone of the State of New York exactly similar to the Pipestone quartzite of Minnesota, and as the latter bears Primordial fossils there is no lack of evidence to parallelize these outcrops. An examination of the quartzites of the Original Huronian convinced the author of the parallelism of the great quartzite there displayed with those of Wisconsin and Minnesota. But things that are equal to the same thing are equal to each other, hence the Huronian quartzite is no other than the Potsdam sandstone of New York, the Red sand rock of Vermont, and the granular quartz of the Taconic.

Irving,[324] in 1888, discusses the classification of the early Cambrian and pre-Cambrian formations, and particularly those of the Northwestern States. The relations of the Baraboo quartzites to the Potsdam sandstone, of the Potsdam to the Keweenawan series, and of the Animikie, Penokee, Marquette, Menominee, and Vermilion Lake iron-bearing series to the underlying and overlying series are again fully discussed. The Keweenawan is held to overlie the Huronian everywhere by a very considerable unconformity. Evidence before given is repeated, and important additional evidence of the break is found in northeastern Minnesota. At the base of the Keweenawan is a great mass of gabbro, which extends from Duluth northeast to the national boundary, more than 100 miles, and at its maximum is more than 20 miles wide. This basal gabbro is now in contact with one member of the Animikie and now with another, while in other places it is in contact with the lower crystalline schists or granite. In the Huronian are placed the Original Huronian, the iron-bearing series of Michigan and Wisconsin, the Black River Falls iron-bearing series, the Animikie series, the St. Louis and Mississippi slate series, the Vermilion Lake iron-bearing series, the Baraboo quartzite series, and the Sioux quartzite series. Under the Huronian is the Laurentian, separated from it by a great unconformity. This is a series of granites, gneisses, hornblende schists, mica schists, and other green schists.

These correlations are held to be warranted both by the lithological likenesses of the rocks in the different districts referred to the same grand division and by the lithological contrasts between the divisions, as well as by the fact that such unconformities as exist between the series must necessarily have a very wide extent. That one or two organic forms have been found in the rocks referred to the Huronian is not sufficient evidence for extending the term Cambrian down to cover this and the Keweenawan groups. In the Huronian are shales and slates which have abundant organic matter, and important beds of ferruginous strata which were probably accumulated because of the existence of organic matter. The fossils discovered are of types which have a great vertical range above the Cambrian and may have as great a vertical range below it. That a pre-Cambrian fauna existed is evident, while it is probable that this fauna had affinities with the Cambrian itself. Such weak paleontological evidence is not sufficient reason to disregard the enormous thickness of the formations to be included in the Cambrian in case the Keweenawan and Huronian are here placed, as well as the two great unconformities below the Potsdam, which must also be covered by this term. Archean is restricted to the pre-Huronian rocks. The volume of the clastic series between the Cambrian and the Archean is such as to demand a term of value equivalent with Paleozoic, and Agnotozoic or Eparchean is proposed as this term.

Van Hise,[325] in 1889, finds the iron ores of the Penokee-Gogebic series to be of sedimentary origin and to have been derived from an original cherty carbonate of iron which is yet abundantly present in the upper horizons of the ore-bearing formation.

Van Hise,[326] in 1891, describes the physical break between a Lower and an Upper Huronian series. In the Marquette district the Lower series includes the lower quartzite and novaculite of Brooks, the limestone formations as well as the chief iron-bearing formation containing the hard ore, which is composed chiefly of jasper and actinolitic and magnetitic slates. The Upper series has at its base a vitreous quartzite, but is chiefly composed of black slates, sometimes carbonaceous, graywackes, and mica schists, together of great thickness, and locally contains belts of ferruginous cherts and slates, including ore bodies, which are, however, of a different character from the ores of the Lower series. The area occupied by the Upper series is equal to or greater than that of the Lower series. That the two series are separated by a great unconformity is shown by numerous contacts.

At these contacts the lower quartzite of the Upper series contains abundant fragments of the Lower series, which had reached their present condition before being deposited in the former. That the Lower series had been greatly folded and deeply truncated before the Upper series was deposited is further shown by the much banded and contorted jasper abutting at all angles against the beds of the uptilted but simply folded Upper series, and also by its more crystalline character.

Since great belts of conglomerates containing abundant fragments of ore and jasper are found in the Upper Vermilion at Ogishki Lake and in the Upper Kaministiquia series, it is argued that the source of this material are the great belts of iron ore and jasper contained in the Lower Vermilion, Hunters Island, and Lower Kaministiquia series. That the Vermilion Lake conglomerate is unconformably above the schists in vertical attitude, bearing ore and jasper, is further indicated by the fact, discovered by Merriam, that on the islands of Vermilion Lake the conglomerate is found to be in a series of gentle folds, although having a vertical cleavage developed. Merriam regards the conglomerate as a comparatively thin formation overlying and overlapping the Lower series. The presence of red jasper conglomerate in the Original Huronian suggests that in this district will be found a Lower series similar to the Lower Vermilion bearing jasper and ore.

It is concluded that the confusion in correlation of the formations about Lake Superior is due to the failure to recognize this general unconformity. Once recognized, the structural conclusions to which the various writers have most steadfastly held are found to be in general harmony. Above the physical break, and constituting the Upper Huronian (equivalent to the Original Huronian) are the Animikie and Upper Kaministiquia, Upper Vermilion, Upper Marquette, western Menominee, Penokee-Gogebic proper, and the Dakota, Iowa, Minnesota, and Wisconsin quartzites, surrounded by the fossiliferous series. In the Lower Huronian are the Keewatin (in part at least), Lower Kaministiquia, Lower Vermilion, Lower Marquette, Felch Mountain iron-bearing series, Menominee proper, the Cherty limestone at the base of the Penokee series, and the Black River Falls iron-bearing schists.

LAWSON,[327] in 1893, on lithological grounds suggests the following hypothetical correlation of certain rocks of western Ontario and Minnesota, eastern Ontario, and Quebec:

Correlation table of Lawson, 1893.

	Western Ontario and Minnesota.	Eastern Ontario.	Quebec.
In order of superposition.	Ontarian system.	Hastings series.	Grenville series.
	Laurentian system.	Ottawa gneiss.	Ottawa gneiss.
	Carltonian anorthosites of Minnesota.		Norian.
In order of chronological sequence, an irruptive rock being of later age than the formations which it invades.	Carltonian anorthosites of Minnesota.		Norian.
	Laurentian system. } Batholithic granites and gneisses.	Ottawa gneiss.	Ottawa gneiss.
	Ontarian system.	Hastings series.	Grenville series.

Winchell (N. H.),[328] in 1893, gives a review of the literature on the Norian of the Northwest. Here are included the gabbros, placed as the basement member of the Keweenawan by Irving, and the rocks of Bohemian Mountains, Keweenaw Point. It is suggested that the anorthosites of Lawson are but facies of the gabbro, and that the two belong together in the Norian.

Van Hise,[329] in 1893, gives an historical sketch of the Lake Superior region to Cambrian time. The five divisions of this region are the Basement Complex or Archean, the Lower Huronian, the Upper Huronian, the Keweenawan (the last three together constituting the Algonkian), and the Lake Superior Cambrian sandstone. These divisions are separated from one another by unconformities.

The Basement Complex consists mainly of (1) granites and gneissoid granites and (2) finely foliated dark-colored banded gneiss or schist. The relations which obtain between the two divisions are frequently those of intrusion, the granites and gneissoid granites being the later igneous rocks. There is no evidence that any of the dark-colored schists are sedimentary, but it is certain, if a massive granular structure be proof of igneous origin, that a part of them are eruptive, for between the two are gradations.

The well-known characteristic rocks of the Lower Huronian are (1) conglomerates, quartzites, quartz schists, and mica schists; (2) limestones; (3) various ferruginous schists, and (4) basic and acidic eruptives, which occur both as deep-seated and as effusive rocks. The order given, with the exception of the eruptives, is the order of age from the base upward. In the Lower Huronian are placed the Lower Vermilion, Lower Marquette, Lower Felch Mountain, Lower Menominee, the cherty limestone formation of the Penokee district, and also probably the Kaministiquia series of Ontario and the Black River Falls series of Wisconsin.

The formations of the Upper Huronian are (1) a basement slate and quartzite, frequently bearing basal conglomerates; (2) an iron-bearing formation, consisting originally of lean cherty carbonate of iron, calcium, and magnesium, and (3) an upper slate. Associated with the sedimentaries in the Michigamme, Crystal Falls, and other districts are great volcanic series, comprising greenstones, agglomerates, greenstone conglomerates, volcanic ash, and amygdaloids. Where these occur the orderly succession is destroyed. Included in the Upper Huronian are the Penokee, Mesabi, Animikie, Upper Marquette, Upper Menominee, and Upper Felch Mountain districts.

The Keweenawan consists of interstratified lavas, sandstones, and conglomerates. The lavas are prevalent at the lower part of the series, interstratifications of the two occur in the middle portions, and the pure detritals exclude the volcanics in the upper portion of the series.

The Lower Huronian is largely crystalline, the Upper Huronian semicrystalline, and the Keweenawan simply cemented. Locally, along axes of intense plication, both the Lower Huronian and the Upper Huronian have been transformed into completely crystalline schists. The Cambrian of Lake Superior is a horizontal sandstone, and rests unconformably upon all the preceding.

WINCHELL (N. H.),[330] in 1895, reviews the stratigraphy of the Lake Superior region. In reference to the Keweenawan series he reaches the following conclusions: (1) The eruptive rocks which in Michigan, Wisconsin, and Minnesota have been included in the Keweenawan consist of two widely differing series of widely separated ages. Included in these pre-Keweenawan eruptives are the great gabbro of Minnesota and the red rocks such as those at the Palisades and at Pigeon Point. This eruptive period is called the Animikie revolution. (2) This period was followed by a long erosion interval, during which were deposited the Sioux quartzites of Dakota, the New Ulm quartzites of Minnesota, the Baraboo and Barron quartzites of Wisconsin, and the quartzites and conglomerates below the Keweenawan diabases in the Penokee district. In the New Ulm quartzites are found "taconite" jasper pebbles, and these are taken as evidence that this material was derived from the Animikie. (3) Following this conglomerate and quartzite is the Keweenawan eruptive age, which separates the *Paradoxides* horizon from the *Dicellocephalus* horizon. (4) The *Olenellus* horizon is separated from the *Paradoxides* horizon by the disturbance that closed the Animikie.

The general succession for the Lake Superior region is given as follows:

Correlation table of N. H. Winchell, 1895.

Upper Cambrian (*Olenellus* zone).		St. Croix. Eastern sandstone. Lake Superior sandstone. Nipigon formation. (The *Dicellocephalus*—"Potsdam" of New York.)	Progressive subsidence.
	Keweenawan (*Paradoxides* zone).	Keweenawan. Traps and underlying quartzite and conglomerate. Potsdam at Potsdam, N. Y., and eastward to Ausable River.	
	Unconformity.		
Taconic (or middle and lower Cambrian).	Animikie (*Olenellus* zone; Foraminifera).	Animikie slates. Pewabic and Wauswaugoning quartzites. Penokee series. Mesabi iron range. Misquah Hills. Gabbro and anorthosite range. Norian. Upper Laurentian. Bohemian range and South Copper range in Michigan. Minong range, Isle Royal.	
The great unconformity.			
Archean.	Ontarian.	Keewatin.	
		Coutchiching.	
	Laurentian.		

The following general conclusions are reached as to the Lake Superior region and other parts of the United States:

The rocks of the Cortland series (the clastics), of the original Taconic area, and of the upper series of the Adirondacks are of the same age—i. e., Taconic, or lower Cambrian.

The basic rocks of the Norian, or Upper Laurentian, system of Canada are of the same age as the gabbros of the Adirondacks.

The Taconic in America embraces all the strata containing any known fossils older than those in the *Dicellocephalus* or Upper Cambrian. It is separated from the Archean by a profound unconformity.

The Animikie strata in Minnesota, and in general the upper iron-bearing series of the Lake Superior region, are of the age of the Taconic.

The Taconic age is represented in the Lake Superior basin, as in New England and Newfoundland, by a great series of quartzites and slates and a few limestones.

Those rocks which have been described and mapped as Keweenawan embrace three eruptive systems, separable by two erosion intervals marked by basal conglomerates and by faunal differences, viz, the eruptives of the Animikie revolution, those of the Keweenawan proper, and those of the regions of Thunder Bay and Black Bay.

It is added as a corollary to the foregoing that the ocean which covered the spot where North America was to exist was subject to forces which acted simultaneously over a very wide area, producing oceanic deposits of like nature and of like succession in widely separated regions; and, again, that some other widely operating forces caused the simultaneous elevation, depression, and finally the breaking of the earth's crust and the escape of vast quantities of basic rock at various points far distant from one another.

WALCOTT,[331] in 1899, discusses markings which have been reported as found in the Huronian iron formation of the Menominee iron district of Michigan. An examination of the specimens indicates that they probably are from the basal detrital material of the Cambrian which rests upon the Huronian iron formation. In the Animikie rocks of the Lake Superior region the evidence of life consists of the presence of graphitic material in the slates and of a supposed fossil mentioned by G. F. Matthew. In the Minnesota quartzite of the Upper Huronian series lingula-like forms and an obscure trilobitic-looking impression are described by Winchell. The latter has been examined and the conclusion is reached that it is of inorganic origin. As to the lingula forms, the weight of evidence is in favor of their being small flattened concretions.

VAN HISE,[332] in 1901, describes the geology of the Lake Superior iron-ore deposits and gives the general succession of formations in the iron-bearing districts. (See table, pp. 328–329.)

Van Hise and others[a] have discussed the geology of the Lake Superior region in previous reports, both general and detailed. The present report is a summary of the earlier reports, but it contains in addition many new features of interest. Attention will be directed only to such conclusions as are new or vary from those given in the preceding reports.

In the Vermilion district the great Stuntz conglomerate and equivalent rocks have been found to lie unconformably under the Animikie series, which has been referred to the Upper Huronian

[a] See especially Principles of pre-Cambrian geology: Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 1, 1896, pp. 571–874; Bull. U. S. Geol. Survey No. 86, 1892; Mon. U. S. Geol. Survey, vols. 19, 1892; 28, 1895, and 36, 1899; and Folio 62, Geologic Atlas U. S., U. S. Geol. Survey, 1890.

by the United States Geological Survey, and thus the Stuntz conglomerate is correlated with the Lower Huronian series instead of with the Upper Huronian, as in former reports. The underlying greenstones, green schists, and iron formation, the latter of sedimentary origin, are thus thrown into the Archean.

In the Mesabi district the Keewatin of the Minnesota Survey, which was in large part classed as Archean by the United States Geological Survey and recognized by all as being unconformably below the Animikie, is subdivided on the basis of recent work in the district by C. K. Leith into an upper series of graywackes, slates, and conglomerates, correlated with the Lower Huronian, and a lower basement complex, consisting mainly of greenstones and green schists, correlated with the Archean. This correlation is based on the equivalence of the Animikie with the Upper Huronian, long maintained by geologists of the United States Geological Survey.

In the Marquette district certain jaspers and associated cherty and slaty rocks found intimately associated with the basement rocks of the Archean and previously supposed to be Huronian rocks infolded with the Archean, are now themselves called Archean.

In the Michipicoten district of Canada the iron formation and associated greenstones and green schists are correlated, respectively, with the iron formation and associated greenstones and green schists of the Vermilion district, and are therefore classed as Archean.

The iron ores of the Lake Superior region are supposed to have originated from iron carbonate in all districts outside of the Mesabi. In the Mesabi district the ores have mainly resulted from the alteration of a green ferrous silicate in small granules, as first shown by Spurr, but the ores have come also in small part from the alteration of iron carbonate, which is correlative in origin with the green granules.' The ferrous silicate granules are believed not to be glauconite as they were named by Spurr.

Van Hise,[333] in 1902, briefly sketches the history of geological mapping in the Lake Superior region, calling attention to the difficulty of preparing accurate maps, and concludes that the maps which have been published from time to time since the earliest map of Foster and Whitney represent reasonably close approximations to the facts as then known, and that notwithstanding their many imperfections they have been of service at the time of publication.

Spurr,[334] in 1902, discusses the origin of the pre-Cambrian iron ores of the Lake Superior region. He repeats his conclusion that the Mesabi ores have resulted from the alteration of a green ferrous silicate of the class of glauconite, and further states that his conclusion in reference to the Mesabi iron formation may be probably applied to most of the other Lake Superior iron ores.

Leith,[335] in 1902, compares the origin and development of the Gogebic and Mesabi iron ores. The ores of the two districts occur in the same geological horizon; they result from the alteration, under weathering conditions, of a ferrous compound of iron, through the agency of percolating waters, and are localized in channels of vigorous circulation of water. But the differences in the development of the ores of the two districts are important. The original ferrous compound of iron is mainly iron silicate in the Mesabi district and iron carbonate in the Gogebic district, although both substances appear in each district. The localization of the ores in the Gogebic district during their concentration has been within clear-cut pitching troughs with definite shapes, while in the Mesabi district the very gentle folding of the iron formation, its fracturing, and the absence of intrusives combine to make the channels of vigorous flow within the iron formation most devious, resulting in the curious and exceedingly irregular shapes now to be observed in the Mesabi ore deposits.

The original ferrous silicate from which the ores develop in the Mesabi district is in minute homogeneous granules, the form of which remains even after the substance is changed. Associated with these granules are undoubted concretions of iron oxide and chert with concentric structure. In the Gogebic district there appear numerous concretions with concentric structure, which Van Hise has shown to develop during the alteration of iron carbonate; and associated with these are rare granules of iron oxide and chert in varying proportions, which may represent altered ferrous silicate granules similar to those of the Mesabi district. Evidences of the existence of original ferrous silicate granules in the Gogebic district are not sufficiently numerous to warrant modification of Van Hise's conclusion that the ores have developed mainly from the alteration of iron carbonate.

Lawson,[336] in 1902, criticises the use of the term Algonkian. He emphasizes the importance of the interval which he calls the Eparchean, between the "Huronian" and Animikie series—that is, between the Lower Huronian and Upper Huronian of the United States Geological Survey—and argues that no one term, such as Algonkian, should include a break of this importance. It is proposed to restrict Algonkian to the Animikie and Keweenawan rocks and to retain Dana's term Archean for all rocks below the Animikie—that is, below the Eparchean interval—and also to retain the terms Laurentian and Huronian as subdivisions of the Archean with the significance originally given them by Logan. The correlations of the Animikie with the Keewatin of Minnesota and with the Upper Huronian of Lake Huron are regarded as erroneous, because of dissimilarity in lithology, in stratigraphy, and in relations to intrusives. Following Willmott and others, it is believed that the Animikie is younger than the (Upper) Huronian series of Lake Huron, and thus later than the

Eparchean interval. Emphasis is placed on the marked lithological similarity in the sedimentary series below the Eparchean break in the Lake Superior and Lake Huron regions and on the probable correlation of these rocks with the Original Huronian series. Summarized in tabular form, the correlation proposed is as follows:

- Paleozoic
  - Cambrian (upper division or Potsdam only).
  - Unconformity.
  - Algonkian
    - Keweenawan.
    - Unconformity.
    - Animikie=Penokee=Upper Marquette.
- Eparchean interval.
- Archean
  - Huronian=Upper Keewatin=Lower Marquette, etc.
  - Unconformity.
  - Laurentian, so called, granite gneisses, etc. (intrusive in the Ontarian) and the Carlton anorthosites.
  - Ontarian
    - Keewatin=Lower Huronian=crystalline schists of south shore invaded by granite gneisses.
    - Unconformity.
    - Coutchiching.

COLEMAN,[337] in 1902, discusses the Huronian question, his argument being mainly against the correlation of the Animikie series of the Lake Superior region with the Upper Huronian series. Evidence that the Animikie is unconformable above his Upper Huronian series is summarized, and emphasis is placed on the point that both the Upper Huronian and the Lower Huronian differ lithologically from the Animikie; they are metamorphosed and schistose as compared with the Animikie, and they are much folded and highly tilted, in marked contrast to the Animikie.

WILLMOTT,[338] in 1902, discusses the nomenclature of the Lake Superior formations, this being practically a consideration of Van Hise's Iron-Ore Deposits.[a] He argues principally against the correlation of the Animikie series with the Upper Huronian of the Original Huronian area. He states that there can be no doubt that Logan in 1863 included within his Huronian two series—the one typically represented by the banded jaspers, the other by the slate conglomerate and the jasper conglomerate. This has been uniformly followed since that time by all Canadian and many American geologists, the vertical green schists and their interbedded banded jaspers being considered Lower Huronian. Willmott doubts the advisability of attempting the separation of the green volcanics and sediments except in limited areas of economic value. Here each would be given formational names, just as Van Hise has done with the Ely greenstone and the Soudan iron formation. In other places the volcanics and eruptives will take the name of the sediment with which they are associated.

[a] Van Hise, C. R., The iron-ore deposits of the Lake Superior region: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 3, 1901, pp. 305–434.

The lowest sedimentary series of the Lake Superior region is the Lower Huronian. These sediments were included in the areas mapped as Huronian by Logan in 1863, and, although not actually found in place by him, were recognized from their fragments, and to him should be given the credit. As so used the term Lower Huronian is nearly equivalent to the term Archean as used by Van Hise, and the term Upper Huronian is equivalent to Van Hise's Lower Huronian. Accordingly the Animikie or the Upper Huronian of Van Hise is younger than the Original Huronian series. That the Animikie is later than the true Upper Huronian or Original Huronian may be shown in the following ways:

1. Stratigraphically it is the third series of sediments upward from the bottom of the geological column in the Lake Superior region; the Upper Huronian is the second.

2. Lithologically the two series are quite different, and so presumably are of different age. There is very little conglomerate at the base of the Animikie; in the Huronian the quartzites, slate conglomerates, and jasper conglomerates are of great thickness. The Oolitic jaspers found in the Animikie are quite absent from the Huronian. The shales, so important in the Animikie, are almost unknown in the Huronian. The laccolithic sills of the Animikie are lacking in the Original Huronian.

3. Structurally the two series are usually said to be alike in that both lie flat and undisturbed. While this is quite true of the Animikie, it is only partially true of the Huronian north of Georgian Bay, and is untrue of the Upper Huronian about Batchawana and Michipicoten. Coleman [a] and Murray [b] have described cases of vertical dip within the so-called Original Huronian, and others have been observed by Willmott. These seem to occur around the outer portion of the Huronian basin, and more gentle dips prevail in the central part. Evidently the Huronian has been subjected to forces which the later Animikie has escaped.

4. Assuming that the large areas of eruptive granite gneisses in the Lake Superior region are of the same age, we find that the Upper Huronian has in many cases been pierced by them, but that the Animikie always overlies them.

Van Hise, Bell, Adams, Miller, and Lane,[88] in 1904, made a six weeks' reconnaissance trip through the Lake Superior–Lake Huron region. These men were selected by the Canadian and the United States geological surveys to attempt to reach some agreement in matters of nomenclature and correlation in the boundary area of the Lake

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[a] Rept. Bureau of Mines, Ontario, 1901, p. 189.
[b] Geol. Survey of Canada, 1858, p. 95.

Superior and Lake Huron regions. The conclusions of the party concerning individual districts are summarized in the sections devoted to those districts. General conclusions concerning the regions as a whole are given in the following statement, quoted from their report:

We do not feel that our examination of the Lake Superior region was sufficiently detailed to warrant an attempt at correlation of the individual formations of the various districts. There are, however, certain general points which seem to be reasonably clear and about which there is no difference of opinion between us. These are as follows:

There is an important structural break at the base of the Keweenawan. The term "Keweenawan" should include substantially all of the areas which have been thus mapped, or mapped as Nipigon, by the Canadian and United States surveys and the State surveys of Michigan, Minnesota, and Wisconsin.

Below the Keweenawan is the Huronian system, which, in our opinion, should include the following series: In the Marquette district the Huronian should include the Upper and Lower Marquette series as defined in the monographs of the United States Geological Survey, or the Upper, Middle, and Lower Marquette series as given in the previous paragraphs. In the Penokee-Gogebic district the Huronian should include the series which has been called the Penokee-Gogebic series proper and the limestone and quartzite which have local development and which we visited east of Presque Isle River. In the Mesabi district the Huronian should include the Mesabi series proper and the slate graywacke conglomerate series unconformably below the Mesabi series. In the Vermilion district the Huronian should include the Knife slates and the Ogishke conglomerates. In the Rainy Lake district the Huronian should include that part of the Coutchiching of the south part of Rainy Lake which is limited below by basal conglomerate, as shown at Shoal Lake. In the Thunder Bay district the Huronian should include the Animikie and the graywacke series in the Loon Lake area. In the Original Huronian area the Huronian should include the area mapped by Logan and Murray as Huronian, except that the Thessalon greenstones should probably be excluded.

Unconformably below the Huronian is the Keewatin. The Keewatin includes the rocks so defined for the Lake of the Woods area and their equivalents. We believe the Kitchi and Mona schists of the Marquette district, the green schist (Mareniscan) of the Penokee-Gogebic district, the greenstone series of the Mesabi district, the Ely greenstones and Soudan formation of the Vermilion district, the part of the area mapped as Keewatin by Lawson in the Rainy Lake district not belonging structurally with the Coutchiching, and probably the Thessalon greenstone series on the north shore of Lake Huron to be equivalent to the Keewatin of the Lake of the Woods, and, so far as this is true, they should be called Keewatin.

For the granites and gneissoid granites which antedate, or protrude through, the Keewatin, and which are pre-Huronian, the term "Laurentian" is adopted. In certain cases this term may also be employed, preferably with an explanatory phrase, for associated granites of large extent which cut the Huronian or whose relations to the Huronian can not be determined.

The following succession and nomenclature are recognized and adopted:

Cambrian—Upper sandstones, etc., of Lake Superior.
    Unconformity.
Pre-Cambrian:
    Keweenawan (Nipigon).[a]
        Unconformity.
    Huronian { Upper (Animikie).
            Unconformity.
        Middle.
            Unconformity.
        Lower. }
        Unconformity.
    Keewatin.
        Eruptive contact.
    Laurentian.

Lane,[339] in 1905, discusses the observations and report of the international geological committee. He disagrees with the committee in believing that the Keweenawan is Cambrian rather than pre-Cambrian, for the following reasons:

1. The Keweenawan is very thick, but this thickness is composed of rocks which may accumulate with extreme rapidity—sandstones, conglomerates, and sheets of trap, single flows of which are hundreds of feet thick—so that geologically it may represent no greater time than the Iceland deposits.

2. Its lithological character is such that fossils would hardly be expected.

3. Intense volcanic activity characterizes its middle and lower parts. Intrusions occur in the lower part. Conglomerates and sandstones are often derived from material of the formation itself. We even find pebbles of Lower Keweenawan agates and intrusives in the Upper Keweenawan.

4. We are therefore prepared to find, as we do, that the lower part has steeper dips, more faults with greater throws, and was evidently much disturbed before the Upper Keweenawan was laid down.

5. The Lower Keweenawan, which is overlain very unconformably by the horizontal Lake Superior (Potsdam) sandstone, also stands in the same relation to the Upper Keweenawan.

6. There is a fairly steady approximation in dip, lithological character, geographical distribution, and degree of disturbance, from the base of the Keweenawan, through its upper members, to the Lake Superior sandstone.

7. This points to one great volcanic epoch, gradually dying out, and one great, generally continuous movement of depression. I do not know of any evidence of uplift and erosion of the Upper Keweenawan before the laying down of the Lake Superior sandstone, which may be conceived as a normally following enveloping mantle, and generally contains practically no material which must and but little that may be derived from this Keweenawan.

8. But along the southern contact of the Copper (Keweenawan) range motion along a great fault line took place, disturbing the unconformable contact between the Lake Superior sandstone and the base of the Keweenawan, probably down to the time of the Niagara, which is caught in the Limestone Mountain syn-

[a] Lane dissents as to the position of the Keweenawan as follows: "The use of the pre-Cambrian above does not imply unanimity in the committee with regard to the pre-Cambrian correlation of the Keweenawan—a topic the committee as such did not investigate."

clinal. Thus the Upper Keweenawan and Lake Superior sandstones are not entirely undisturbed.[a]

To sum up, I have not been able to find other strata or unconformities or indications of time interval to represent the Middle and Lower Cambrian between the Lake Superior sandstone and the Upper Keweenawan.

The distribution and relations of the Ajibik and Mesnard quartzites, as shown by recent work, are discussed. Faulting is believed to be more important than previously thought. At one place the so-called Laurentian of the Marquette district has been found to be intrusive into the Huronian. Intrusive and effusive igneous rocks are to be found in formations other than those mapped by the United States Geological Survey, and more work needs to be done in separating the intrusive from the effusive phases.

Observations on the grain of rock, based on the hypothesis that the grain shows a definite relation to distance from margin and temperature of the intruded rock, show that the Laurentian granites visited by the committee, and especially those of the Rainy Lake district, are in all respects analogous to plutonics generally. While the intruded strata were nearly or quite fused and softened, the intruding rocks were considerably superfused and were therefore not the immediately subjacent strata.

Leith,[340] in 1906, summarizes the general geology of the Lake Superior region, with particular reference to the iron-bearing series.

SECTION 6. SUMMARY OF PRESENT KNOWLEDGE OF LAKE SUPERIOR REGION.

INTRODUCTION.

The geology of the Lake Superior region is of peculiar interest from both an economic and a scientific standpoint. The presence of large and rich iron and copper deposits has made a knowledge of the geology of the region necessary for purposes of exploration and exploitation. The ores of the region are contained in rocks of pre-Cambrian age, which present an unusually full succession and great variety. It has been possible, with the large expenditures which the magnitude of the mining industry warrants, to work out the stratigraphy more satisfactorily than in almost any other area of pre-Cambrian rocks.

The real complexity of Lake Superior geology, the confusion of names, and the multiplicity of reports covering small parts of the region are such that interested persons, other than geologists directly engaged in the mapping, may well hesitate to attempt to comprehend

[a] In fact, the Lake Superior basin has probably been a concave portion of the earth crust and therefore incapable of accumulating notable stress through all geologic time, and thus always susceptible to slight adjustments. See Chamberlin and Salisbury, Geology, vol. 1, p. 561.

Correlation of pre-Cambrian rocks

		Series.	Mesabi district.	Penokee-Gogebic district.	Vermilion district.	Marquette district.
Algonkian.		Keweenawan series (copper bearing).	Great basal gabbro and granite.	Gabbros, diabases, etc.	Gabbro.	
Algonkian.	Huronian series.	Upper Huronian (iron bearing).	Virginia slate. Biwabik formation (iron bearing and productive). Pokegama quartzite.	Tyler slate. Ironwood formation (iron bearing and productive). Palms formation (quartz slate).	Rove slate. Gunflint formation (iron bearing, but nonproductive).	Michigamme slate (locally replaced by Clarksburg formation). Bijiki schist (iron bearing). Goodrich quartzite, containing productive detrital ores at its base.
Algonkian.	Huronian series.	Middle Huronian (iron bearing).	Lower-middle Huronion. Granite incrusive in lower formations. Slate graywacke conglomerate formation.		Lower-middle Huronian: Intrusives. Knife Lake slate. Agawa formation (iron bearing, but nonproductive). Ogishke conglomerate.	Negaunee formation (iron bearing and productive). Siamo slate. Ajibik quartzite.
Algonkian.	Huronian series.	Lower Huronian.		Limestone of Bad River. Quartzite.		Wewe slate. Kona dolomite. Mesnard quartzite.
Archean or basement complex.		Laurentian series (intrusive into Keewatin).	Granites and porphyries.	Granite and granitoid gneiss.	Intrusive granites, porphyries, and greenstones.	Granite, syenite, peridotite. Palmer gneiss.
Archean or basement complex.		Keewatin series (iron bearing).	Greenstones, green schists, and porphyries.	Greenstones, green schists, and fine-grained gneiss.	Soudan formation (iron bearing and productive). Ely greenstone, an ellipsoidally parted basic igneous and largely volcanic rock.	Kitchi schist and Mona schist, the latter banded, and in a few places containing narrow bands of nonproductive iron-bearing formation.

of the Lake Superior region.

Crystal Falls district.	Menominee district.	Keweenaw Point.	Michipicoten.	Other parts of Ontario north of Lake Superior.
		Middle and upper Keweenawan. Interbedded lavas and sediments grading up into sandstones.		Interbedded sediments and traps along Lake Superior shore.
Michigamme slate, containing a productive iron-bearing horizon not separated in mapping for much of the district. With basic volcanics. —(Unconformity?)—	Hanbury slate, bearing in lower portions calcareous slates, etc., containing siderite and iron oxide. Vulcan formation, consisting of three members: Curry iron-bearing member, Brier slate member, Traders iron-bearing member. —(Unconformity?)—			Animikie group of northwest shore, comprising iron formation overlain by slate.
Hemlock formation (basic volcanic). Randville dolomite. Sturgeon quartzite.	Randville dolomite. Sturgeon quartzite.		Lower-middle Huronian: Basic eruptives. Acidic eruptives. Dore conglomerate.	Lower-middle Huronian: Undivided pre-Animikie sediments, mainly graywackes, slates, and conglomerates, much metamorphosed.
Granite.	Granites and gneisses.		Granites and gneisses.	Granites and gneisses.
	Quinnesec schist.		Eleanor slate. Helen formation (iron bearing and productive). Wawa tuff. Gros Cap greenstone.	Greenstone and iron formation, similar to that of Vermilion district of Minnesota.

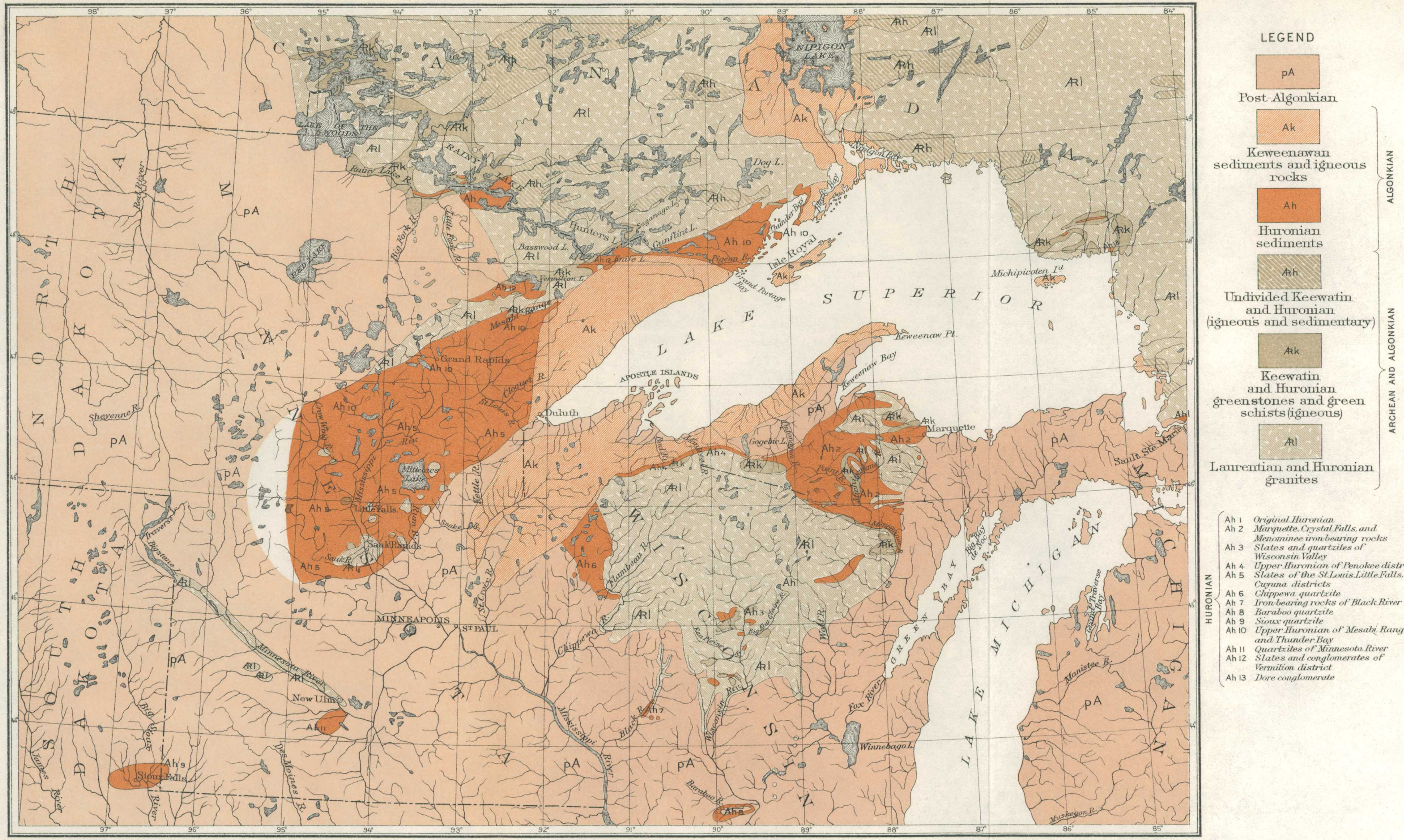
the geology of the region as a whole. In the following summary an attempt will be made to sketch in a somewhat elementary way the outlines of the geology of the Lake Superior country. (See Pl. II.)

Geological information concerning the region has been gathered by mining companies and by the geological surveys of Michigan, Wisconsin, Minnesota, Ontario, Canada, and the United States. Perhaps in no other part of the country have the mining men themselves spent so large sums in purely geological work. This has resulted in the publication of reports and maps by the State and Federal surveys in much less time and at far less cost than would have been otherwise possible. The United States Geological Survey is the only organization which has covered all of the districts on the United States side of the boundary, and as its reports include the information gathered by the mining companies and State organizations special reference is made to these reports. The work of the Survey was begun in the early eighties, in charge of R. D. Irving, and has been continued since 1888 by C. R. Van Hise and his assistants. The results of their work appear in a series of detailed monographs and maps on each of the principal producing ore-bearing districts. A final general monograph on the Lake Superior region, accompanied by revised maps of each of the districts and a general geological map of the region, is in preparation.

Geological work has been much less detailed in the Canadian portion of the Lake Superior region, largely because the ore-bearing districts thus far discovered have not seemed to warrant such large expenditures for geological work as have been made on the United States side of the boundary, but also because the small appropriations made by the Dominion and Provincial governments for geological work must be made to cover enormous areas, thus preventing expensive detailed work in one area. The Michipicoten district is the only ore-bearing district in Canada which has been mapped and described in any considerable detail, although much has been written on the general geology of the north shore of Lake Superior.

The ore-bearing districts themselves comprise but a small portion of the Lake Superior region as a whole, but they are the areas in which the fullest successions of pre-Cambrian rocks are exposed. The intervening areas are less well known. It has been possible to correlate with reasonable certainty the rock series of the different districts, although the geology of each of the districts has been worked out in large part independently. But because of the considerable, less well-known areas separating the closely studied districts, it is difficult at the present time completely to unify the geology of the region.

The confusion of names and correlation has made an understanding of Lake Superior geology very difficult. In the hope of reaching a common basis of nomenclature and correlation, a joint committee of geologists of the United States, Michigan, Canadian, and Ontarian



Compiled from maps of United States, Canadian, Minnesota, Michigan, Wisconsin, and Ontario surveys.

MAP OF PRE-CAMBRIAN ROCKS OF THE LAKE SUPERIOR REGION

Scale

0 50 100 150 miles

1907

geological surveys visited crucial areas about Lake Superior in 1904. Their recommendations are followed in this report. They will be followed also in the reports of the Canadian, United States, Ontarian, and Michigan geological surveys. The general succession upon which the committee agreed has already been given. (See p. 326.)

The table on pages 328–329 presents the detailed succession and correlation of the series in the various Lake Superior districts under the classification adopted by the joint committee. It presents also a major grouping of the committee's units into Archean and Algonkian, concerning which the committee made no recommendation. Reasons for this grouping are given later (pp. 356 et seq.).

ARCHEAN SYSTEM, OR BASEMENT COMPLEX.

The oldest system of rocks in the Lake Superior region has very great lithological complexity. It was formerly supposed to consist largely of plutonic granites and gneisses and surface equivalents, with but subordinate amounts of basic igneous rocks, but it is now known that the system includes large quantities of intermediate and basic igneous rocks, both plutonic and surface phases, and also one or more sedimentary formations. The abundant rocks are granites, syenites, acidic porphyries, basalts, gabbros, peridotite, and a great variety of schists and gneisses—micaceous, hornblendic, and chloritic. Jaspilites, iron ore, and slates are present in subordinate amounts. Many of the schists and gneisses result from the alteration of the above-named rocks. It is not possible fully to state the stratigraphic relations of the rocks, but it is certain that a series of rocks known collectively by the terms greenstones and green schists are the oldest, that associated with them and perhaps in part later and above these is an iron-bearing formation with associated slate, and that intrusive into both the basal greenstones and the sedimentary rocks are great masses of acidic igneous rocks. The basic and intermediate igneous rocks, commonly referred to as greenstones and green schists and characterized by a prevailing green color, with their associated slates and iron formation, will be called Keewatin series, following the recommendation of the international geological committee. The acidic rocks, including granites, gneisses, and acidic schists, characterized by prevailing reddish or light colors, will be called Laurentian series.

One of the conspicuous features of the greenstones and green schists of the Keewatin is the presence of ellipsoidal, spherulitic, and pyroclastic phases, indicating their essential surface volcanic origin. The basement upon which they were deposited has not been found. It is an interesting fact, then, that the oldest rock in the Lake Superior region, and perhaps the oldest pre-Cambrian rock with definitely determined age in the country, is of surface volcanic origin, and that the character of the basement upon which it was deposited is unknown.

The nature and distribution of the Archean rocks for different parts of the region are discussed in subsequent paragraphs.

Michigan and Wisconsin.—In Michigan and Wisconsin the Keewatin rocks cover extensive areas, although subordinate in amount to the Laurentian. A considerable area of Keewatin rocks is found in the northern part of the Marquette district. This area includes various green schists, among which are chloritic and micaceous schists, resulting from the alteration of basic and intermediate rocks which present evidences of surface volcanic origin and perhaps of deposition under water. Where strongly schistose or gneissic the rocks have been called the Mona schist, and where coarser and giving evidence of derivation from surface volcanics they have been called the Kitchi schist. Associated with the green schists of the Marquette district are various nearly massive igneous rocks, among which peridotite is important. There are also small areas of jasper and carbonate rocks, formerly supposed to be of the nature of ferruginous vein material, but now believed to represent a sedimentary iron formation infolded or interbedded with the other rocks of the Keewatin.

Green schists similar to those of the Marquette district occur south of the Menominee district and have been known as the Quinnesec schist. They contain tuffaceous and fragmental phases similar to those of the Kitchi schist of the Marquette district. The excellent description of them by G. H. Williams in Bulletin 62 of the United States Geological Survey has become classic. Their relations to the Huronian sediments can not be seen in the Menominee district proper, but to the west along Pine River they have been found to be unconformably beneath upper Huronian sediments. Because of this and of their occurrence on the south side of the Menominee syncline, containing lower Huronian rocks, they are assigned to the Keewatin.

Similar rocks on the north side of the Menominee district near Twin Falls, mapped by Bayley and Van Hise as equivalent to the Quinnisec schist (Keewatin), have been subsequently found to be intrusive into the upper Huronian. The same is true of greenstones along Brule River to the west.

South of the Penokee-Gogebic district are two areas of Keewatin schists, including micaceous, chloritic, and hornblendic varieties, which have been known respectively as the eastern and western green schist areas.

In Michigan and Wisconsin the predominating rocks of the basement complex are Laurentian granites and gneisses, which appear both north and south of the Marquette district, within the Crystal Falls district and east of it, north and south of the Menominee district, and south of the Penokee-Gogebic district. These granites and gneisses show a variety of characters and are certainly not all of the same age, although with minor exceptions they antedate the Algonkian rocks. One of the areas of acidic rocks on the south side of the

Marquette district has been discriminated under the name Palmer gneiss. The characters of this rock are peculiar and it is possible that it may represent in part a much altered acidic sediment. It is certain that some of the rocks mapped as Palmer gneiss are sedimentary, but such sedimentary rocks really belong to the Algonkian and have been included in the Palmer gneiss because of errors in mapping. How far into Wisconsin these basement complex granites and gneisses extend is not known. In north-central Wisconsin granites of apparently similar characters have been found to be later than the basement complex, and it is not known where in the great granitic area extending from central Wisconsin to the State boundary the line between the granites of the basement complex and the later granites should be drawn.

Central and eastern Minnesota.—In this region, along Minnesota, Mississippi, and Snake rivers, are areas of granite, gneiss, massive greenstone, gabbro, hornblendic schist, micaceous schist, etc., which have been in the past referred to the Archean. Hall, however, concludes that certain of the schists have resulted from the intrusion of granite into the Huronian sediments, as typically developed at Carlton and Cloquet, and thus that most of the acidic igneous rocks are of Algonkian age. Certain of the massive greenstones running eastward from Mississippi River are older than the granites and lithologically resemble the Keewatin greenstones in the Mesabi and Vermilion districts. These are accordingly mapped as Keewatin, while the granites are mapped as Algonkian.

Mesabi district.—In the Mesabi district the Archean is represented by several comparatively small areas of Keewatin greenstone and green schist, comprising ellipsoidal basalt and hornblendic, chloritic, and micaceous schists, intrusive into which are granite porphyries in small quantity.

Vermilion district.—In the Vermilion district the Keewatin series of the Archean is mainly represented by greenstone, much of which is ellipsoidal basalt, in some cases showing surface phases. It occurs in great oval-shaped areas wholly or partly surrounded by sediments. Closely associated with the greenstones in relatively small lenses and bands is the other chief rock of the Keewatin, the iron-bearing Soudan formation, which includes jaspilite, iron ore, and slate. The relations of the iron-bearing formation and greenstone have been much studied, but with only partially positive results. The iron-bearing formation is almost certainly sedimentary, because of its association and interstratification with slates and because of the similarity to other known sedimentary iron-bearing formations of the Lake Superior region; and yet, with the exception of a trivial amount of slate and conglomerate at one or two places, the jaspilites, making up the great mass of the formation, rest with sharp contact against the greenstone without intervening fragmental material. Mining operations and the surface distribution of the iron-bearing formation, particularly the occurrence of the main belts in synclinal areas adjacent to lower Huronian sediments, indicate that this formation, in many places at least, rests on top of the greenstone and has been infolded with it; but there is little opportunity to determine the relations of many of the iron-formation bands, and it has been thought probable that some may be interbedded with greenstone flows. Indeed, interbedding seems almost certainly to explain the relations of the greenstone, iron formation, and Huronian sediments at the east end of the Ely iron-bearing trough. In this connection it is interesting to note that at Schreiber Bay, on the north shore of Lake Superior, a well-bedded iron-bearing formation of the Animikie group rests on granite without intervening fragmental material, although a short distance away separating clastic material is found.

As elsewhere, the Laurentian series of the Archean in the Vermilion district is intrusive into the greenstones and iron formation of the Keewatin. It consists of granite porphyries and granites, the latter chiefly almost massive, but showing subordinate amounts of schistose granite. The granites occur for the most part in the great area lying north and east of the Vermilion range. Immediately adjacent to the range they are known as the "Vermilion Lake," "Trout," "Burntside," "Basswood," and "Saganaga Lake" granites. Along the contact of the Keewatin there are considerable belts of hornblendic schist and gneiss, which are the Keewatin, metamorphosed by and intermingled with the granite. The granites of Vermilion Lake presumably extend northward into Canada and connect with granites mapped by the Canadian geologists, but again information is not available which will allow the drawing of boundaries between granite belonging to the basement complex and granites of later age, considerable masses of which appear in the Canadian districts to the north.

Lake of the Woods and Rainy Lake.—In the districts of Lake of the Woods and Rainy Lake the Keewatin series of the Archean is well represented, occupying a large part of the area mapped in detail. Indeed, the name Keewatin was first applied to the rocks of this series by Lawson in the Lake of the Woods area. The Keewatin consists of massive and schistose greenstones with ellipsoidal and surface phases, perhaps in part water deposited, and contains small amounts of normal, black, sedimentary, and apparently interbedded slate. Iron-bearing formation similar to that in the Vermilion district is apparently lacking, but in its place are narrow layers and lenses of cherty and ferruginous dolomite, less than 3 feet wide, which have almost identically the same relations with the greenstones and green schists as has the iron-bearing formation in the Vermilion district. The series is intruded and highly metamorphosed by Laurentian granite and gneiss. Lawson holds that the Laurentian granite represents fused Keewatin rocks. The writers believe that the relations clearly exhibited at the contacts of the Laurentian and Keewatin are those of normal igneous intrusion, and that there is no evidence presented to warrant an appeal to subcrustal fusion to explain the relations. (See observations of Van Hise and Lane, pp. 284, 294–295, 324–327.)

Michipicoten district.—The Archean of the Michipicoten district presents close similarities to the Archean of other parts of the Lake Superior region, especially of the Vermilion district. It consists of Keewatin greenstones with ellipsoidal and other surface structures, of tuffs, both basic and acidic, of an iron-bearing formation, and of slate, all intruded by Laurentian granites and gneisses. The iron-bearing formation is believed to be the counterpart of that seen in the Keewatin in the Vermilion and Marquette districts and elsewhere in the Lake Superior region.

Other points on the north shore.—Greenstones and green schists with associated slates and iron formation, similar in many respects to those of the Michipicoten and Vermilion districts, are known in many areas in Ontario. They are typically developed in the Mattawan, Atikokan, and Steep Rock Lake iron ranges, northwest of Lake Superior.

ALGONKIAN SYSTEM.

The full succession of the Algonkian system for the Lake Superior region comprises four unconformable sedimentary divisions, all of them being associated with igneous rocks. The three lower divisions are collectively referred to the Huronian series; the upper is the Keweenawan series. All are unconformably above the basement complex and unconformably below the Paleozoic for the region. In no district are all of these series represented. While there are similarities between the Huronian series of the different districts which are believed to warrant their correlation, the differences are such as to make it desirable to discuss the Huronian successions of the individual districts separately, in order to avoid the impression of finality in correlation, which would inevitably tend to obscure or perhaps distort the facts. The Keweenawan series is essentially a unit for the region and it is so described on a subsequent page.

HURONIAN SERIES.

Marquette district.—In the Marquette district all three groups of the Huronian series are present. They have been locally called the "Lower Marquette," "Middle Marquette," and "Upper Marquette," but these terms are now superseded by lower Huronian, middle Huronian, and upper Huronian. Prior to 1904 the middle Huronian and lower Huronian had been mapped together as "Lower Huronian," but the discovery of a great unconformity within the old "Lower Huronian," by A. E. Seaman, showed that it really consists of two groups. The lower Huronian consists of three formations—in ascending succession the Mesnard quartzite, the Kona dolomite, and the Wewe slate—together ranging from 1,200 to 3,000 feet in thickness. The middle Huronian includes, from the base up, the Ajibik quartzite, the Siamo slate, and the iron-bearing Negaunee formation, together ranging from 1,900 to 3,000 feet in thickness. The iron-bearing Negaunee formation carries the important iron-ore deposits of the district. The upper Huronian includes, in ascending succession, the Goodrich quartzite, the iron-bearing Bijiki schist, and the Michigamme slate. The Bijiki schist, appearing principally in the western part of the district, and the Goodrich quartzite, appearing principally in the central part of the district, are taken to be partly equivalent in age. The Bijiki schist contains iron ores at one or more horizons. Extrusion of volcanic rocks, the Clarksburg formation, began in middle Huronian time and extended into upper Huronian time. Dikes and bosses of basic igneous rocks are abundant in both the lower and middle Huronian.

The lower Huronian is the most folded and metamorphosed, the upper Huronian the least; the lower Huronian is the thinnest of the series, the upper Huronian the thickest; the lower Huronian occupies the least area, the upper Huronian the greatest. The unconformities between the middle and lower Huronian and between the upper and middle Huronian are indicated by basal conglomerates and truncation of the underlying rocks. It can not be said at the present time which of the two unconformities is the more important.

Crystal Falls district.—In Clements's monograph on the Crystal Falls district[a] the Huronian rocks were divided, on the map and in the text, into the upper Huronian and lower Huronian, corresponding to the old division of "Upper Marquette" and "Lower Marquette" for the Marquette district. The lower Huronian consists, from the base upward, of the Sturgeon quartzite and the Randville dolomite, varying from 600 to 1,600 feet in thickness. Cutting and resting on both formations is the Hemlock formation, consisting largely of basic volcanics. Interbedded in this formation is the "Mansfield" slate. The upper Huronian comprises the Michigamme slate, containing an iron-bearing horizon not separated in mapping for much of the district.

There is practically no direct field evidence of unconformity between the Hemlock formation and the upper Huronian slates, the existence of the break having been inferred from the difference in lithological character and from supposed correlation with the Marquette district.

[a] Mon. U. S. Geol. Survey, vol. 36. 1899.

The series have been folded into complex folds, the trend of the closer folds varying from north-south to east-west. The closer folds in the northeastern part of the district are nearly north-south; in the central part, northwest-southeast; in the eastern and southeastern parts, nearly east-west. All of these folds have steep pitches.

Menominee district.—The Huronian rocks of this district have been divided into the "Lower Menominee" and "Upper Menominee." These terms are now discarded in favor of lower Huronian and upper Huronian. The lower Huronian comprises the Sturgeon quartzite and Randville dolomite, in all respects similar to formations of this name in the Crystal Falls district and similar respectively to the Mesnard quartzite and the Kona dolomite of the lower Huronian of the Marquette district. A middle Huronian has not been found, although iron-formation pebbles, supposed to represent it, are found in the conglomerate at the base of the next overlying group. The upper Huronian comprises (1) the Vulcan formation, consisting of three members, in ascending order (*a*) Traders iron-bearing member, (*b*) Brier slate member, and (*c*) Curry iron-bearing member, and above this (2) the Hanbury slate, bearing in lower portions calcareous slates, siderite, and iron oxide. The thickness of the Vulcan formation averages 650 feet. The thickness of the Hanbury slate is uncertain, but is thought to be 2,000 to 3,000 feet. There seems to be an unconformity between the upper and lower Huronian, marked by a basal conglomerate but not by structural discordance or evidence of extensive intervening erosion.

In the Menominee district the structure has been described as a northwest-southeast trending synclinorium with a minor anticlinal roll which brings up the older formations in the central portion of the district. However, attention is directed to the fact that the lower Huronian, which ought to appear on the south side of the trough, is here missing, and the synclinal structure is inferred rather than actually observed.

Penokee-Gogebic district.—In the Penokee-Gogebic district are found representatives of the lower Huronian and upper Huronian, with intervening unconformity. The middle Huronian seems to be lacking. The lower Huronian comprises a lower quartzite overlain by a cherty limestone (the latter well exposed along Bad River), similar respectively to the Mesnard quartzite and the Kona dolomite of the Marquette district. The upper Huronian (also called "Penokee-Gogebic series") comprises, from the base up, the Palms formation, the iron-bearing Ironwood formation, and the Tyler slate, possibly 13,300 feet in thickness. Much the largest portion of the district is occupied by the upper Huronian rocks, principal in volume among which is the slate. Intrusive into the upper Huronian are diabase dikes, probably of Keweenawan age. The principal rocks of the district, the upper Huronian, strike in general east-northeast and dip from 35° to 80°, averaging perhaps 65°, N.

Iron River and vicinity.—In the broad triangular area between the east end of the Penokee-Gogebic district and the Marquette, Crystal Falls, and Menominee districts is a great slate formation constituting the upper part of the upper Huronian. In isolated areas within this slate appear iron ores, productive at Iron River and Florence. Locally there appear also older Huronian sediments, the correlation of which is doubtful. Finally, at various places within this district are areas of basic volcanics, the structural relations of which are for the most part obscure. The volcanic rocks of Brule River in the southern part of the Iron River district are probably Keewatin, while the remainder are upper Huronian, with the exception of a short extension of the Hemlock formation (lower Huronian) into the east side of the district.

Northeastern Wisconsin.—Extending southwest from the Menominee district into north-central Wisconsin is an area containing Algonkian rocks with indefinite limits. This area contains considerable masses of quartzite and greenstone schists, the latter probably belonging to the basement complex.

North-central Wisconsin.—In north-central Wisconsin are two unconformable sedimentary groups, tentatively correlated by Weidman with the middle Huronian and lower Huronian. These rest unconformably upon a Laurentian complex of granite, gneiss, syenite, and diorite. The lower of the two Huronian groups is intruded by great masses of rhyolite, diorite, gabbro, peridotite, granite, syenite, and related rocks, these making up 75 per cent of the entire area.

Chippewa River and Barron County.—In Chippewa and Barron counties are quartzites apparently of two ages. These quartzites are similar to those of the Huronian of Michigan. The slight metamorphism and the geographical relations of the upper quartzite with the Gogebic phase of the Penokee group suggest its upper Huronian age.

Central Minnesota.—In the vicinity of Carlton, Cloquet, and Little Falls, Minn., and extending to the southwest, is a considerable area of well-banded graywacke and slate similar in all respects to the upper Huronian of the Mesabi district to the north. Where they become hornblendic and micaceous Hall believes them to be the result of metamorphism of the graywacke and slate by intrusive granite.

Near Dam Lake, south of Kimberly, is a quartzite exposure which has been correlated with the upper Huronian of the Mesabi district.

In the Cuyuna district to the west, in the vicinity of Deerwood and Brainerd, extensive drilling through a thick drift covering has shown the presence of an iron formation containing iron carbonate, iron ore, and ferruginous chert phases, underlain by magnetic quartz schist and overlain by slate, which is continuous with that at Carlton and Cloquet. Diabase, gabbro, and granite are found in close association. They are probably intrusive, although development work has not proceeded far enough to prove this. The rocks are weathered deeply and covered by Cretaceous conglomerate, indicating a correlation of the weathering with the Cretaceous peneplain. It is believed that these rocks are to be correlated with the upper Huronian of the Gogebic district and that they are in general along the southern margin of the Mesabi syncline. The district is complexly folded. Similar rocks are found by drilling to the southwest, west, and northwest.

Along Minnesota River are quartzites similar to the Huronian quartzites of Michigan, but to which part of the Huronian is unknown.

Mesabi district.—In this district a twofold classification of the Huronian series is possible. The upper part corresponds with the upper Huronian of Michigan and Wisconsin, while the lower part might be equivalent to either the lower or the middle Huronian of Michigan, or to both. It will be here referred to as the lower-middle Huronian.

The unconformity between the upper and the lower groups is, as usual, a great one. The lower-middle Huronian consists of conglomerates, graywackes, and slates, with bedding and schistosity vertical and striking east-northeast. It occurs in but small areas. It is intruded by the Giants Range granite, which constitutes the main topographic feature of the Mesabi range. The upper Huronian (or Animikie group) comprises from the base up the Pokegama quartzite (200 feet), the iron-bearing Biwabik formation (1,000 feet), and the Virginia slate, of great but unknown thickness. This group rests on the south slope of the Giants range, strikes east-northeast, dips for the most part southerly and southeasterly at angles varying from 5° to 20°, and is gently cross folded, the axes of the cross folds pitching in the direction of the general dip noted. At the east end of the district granite and basic igneous rocks of Keweenawan age are intrusive into this group in the form of sills and dikes. Here the upper Huronian is highly metamorphosed and tilted to an angle of 45° S.

Vermilion district.—In the Vermilion district only a twofold classification of the Huronian is possible, the groups corresponding very closely in lithology and structure with the groups of the Mesabi district, although varying greatly in the magnitude of the respective areas. The lower-middle Huronian sedimentary rocks consist of conglomerate, slate, and graywacke and occupy large areas in this district. Usually the group appears in belts between and surrounding the cores of greenstone belonging to the basement complex. The schistosity and bedding stand nearly vertical and strike east-northeast. This group is intruded by granite masses, such as the Giants Range, Cacaquabic, and Snowbank granites and the granite of White Iron Lake. The upper Huronian occurs only in the east end of the district, where the westward continuation of the upper Huronian of the Gunflint district laps diagonally and unconformably across the east end of the Vermilion district. The upper Huronian here is similar in all respects to the metamorphosed upper Huronian of the east end of the Mesabi district.

Rainy Lake.—In the Rainy Lake area is a series dominantly of micaceous schists, grading downward near its base into green hornblendic and chloritic schists, and these in turn into conglomerates. This series rests unconformably upon the Keewatin and Laurentian rocks. It is lithologically similar to the series mapped as lower Huronian in the Vermilion and Mesabi districts of Minnesota and in the Michipicoten and other districts of Ontario. It was originally mapped by Lawson under the name "Coutchiching" and in small part under the name "Keewatin." He supposed the "Coutchiching" series to underlie the Keewatin series, but the reverse relations were shown by Van Hise in 1898 and were confirmed by the observations of the international geological committee in 1904. This series is now called Huronian, and the term "Coutchiching" has been dropped. Its use has led to much confusion because of Lawson's misapprehension of the stratigraphic position of the series to which he applied the term, and because the term was subsequently used by other geologists in Ontario and Minnesota to cover metamorphosed igneous and sedimentary rocks of various ages, including metamorphosed Keewatin rocks. The nature of certain of the conglomerates in the Huronian of the southwestern shore of Rainy Lake seems to indicate the possibility that both lower Huronian and middle Huronian are here represented, but this is not certain.

Steep Rock Lake.—Smyth describes the Steep Rock "series" as consisting from the base up of conglomerate, limestone, ferruginous formation, probably volcanic ash, interbedded crystalline traps, calcareous green schist, upper conglomerate, greenstones and greenstone schists, agglomerate, and clay slate. The estimated thickness for the whole group is 4,500 feet. It is believed that all of these rocks are older than the Animikie or upper Huronian, but whether they comprise one or two groups is not known. Possibly from Smyth's description both the middle and lower Huronian are represented. The whole rests unconformably upon Laurentian granite and gneisses and Keewatin schists.

Hunters Island and region northwest, north, and northeast.—In the Hunters Island area graywackes, slates, and conglomerate, similar in all respects to the lower-middle Huronian of the Vermilion district of Minnesota, have been observed at several localities. In the mapping of the Vermilion district by the United States geologists the lower-middle Huronian was traced continuously to the northeast for some 15 miles into Hunters Island. Along the line of the Canadian Northern Railway similar sediments may be observed in the Mattawan and Atikokan districts. The published Canadian maps of this great region for the most part discriminate only between the granites and the green rocks, the latter including both Keewatin and Huronian, as the terms are here used.

International boundary and north shore of Lake Superior.—Extending from the east end of the Vermilion district in the vicinity of Gunflint Lake eastward to Pigeon Point and northeastward to the head of Thunder Bay on Lake Superior, and thence in discontinuous areas past Nipigon Bay, is a great area of upper Huronian or Animikie rocks similar in all respects to the upper Huronian rocks of the Mesabi district and of the south shore, except that the iron-bearing and quartzite members are not so well developed and the series is more largely intruded parallel to the bedding by Keweenawan sills of basic igneous rock, known as the Logan sills. A narrow belt of lower-middle Huronian sediments has been recently found by W. N. Smith north of the Animikie rocks to the east of Thunder Bay.

Michipicoten district.—Rocks of lower-middle Huronian age, consisting of conglomerate (Dore conglomerate), graywacke, and slate, associated with basic and acidic eruptives, similar in all respects to the lower-middle Huronian of the Vermilion district, are here present. They are intruded by granites and gneisses mapped as "Laurentian" under the old usage of the Canadian geologists.

KEWEENAWAN SERIES.

The Keweenawan is the upper of the two series of the Algonkian system in the Lake Superior region. The most characteristic feature of the Keweenawan is that abundant effusive rocks are as widespread as the series itself; indeed, they probably compose from a third to a half of the series. The Keweenawan contrasts with the Huronian in that in the latter series the effusive rocks are largely concentrated in a number of localities, although in these areas they may be of very great thickness. In short, the Keweenawan was a period of regional volcanic activity, while the Huronian was a period of local volcanism.

DISTRIBUTION.

The Keweenawan rocks border the major part of the shore of the western half of Lake Superior, occupy islands in the eastern half, and are found on the mainland at the extreme eastern end of the lake. For the western half of the lake these rocks extend inland from a few miles to 125 miles, and here are the important districts of the region. This distribution shows that this series once occupied the major portion of the Lake Superior basin and from it extended varying distances, although for much of the basin at the present time the Keweenawan rocks may be overlain by the Cambrian sandstone.

The chief areas of the Keweenawan are (1) those of Black and Nipigon bays and Lake Nipigon, (2) northern Minnesota, (3) northern Wisconsin, and (4) northern Michigan. Subordinate areas are (1) Isle Royal, (2) Michipicoten Island, (3) Mamainse Peninsula, and other points on the east shore of Lake Superior. Irving estimated the area of the Keweenawan without the intrusives in the older series at 41,000 square miles.

It is thus evident that Lake Superior in Keweenawan time was an area of regional volcanic activity extending east-west for more than 400 miles and north-south scarcely a less distance.

SUCCESSION.

A broad study of the various districts of the Keweenawan leads to the conclusion that a threefold division of the series as a whole may be made as follows, beginning at the bottom: (1) Lower Keweenawan, comprising conglomerates, sandstones, dolomitic sandstones, shales, and marls; (2) middle Keweenawan, comprising extrusive and intrusive igneous rocks, with important amounts of interstratified sandstones and conglomerates and subordinate amounts of shale; and (3) upper Keweenawan, comprising conglomerates, sandstones, and shales. In the region of Black and Nipigon bays and in northern Minnesota the lower and middle groups appear. In Michigan and Wisconsin the lower, middle, and upper groups are found. On Isle Royal and Michipicoten Island only the middle group is known, and to the eastern side of Lake Superior the lower and middle groups appear. Thus in only one district is the full succession known.

LOWER KEWEENAWAN.

The lower Keweenawan is found in all of those districts in which the succession extends to the bottom of the series. However, by far the most important area of the lower Keweenawan is that on Black and Nipigon bays. The rocks are here a series of quartzose sandstones, dolomitic sandstones, and red marls, which have a thickness estimated by Logan to be from 800 to 900 feet and by Bell to be from 1,300 to 1,400 feet. In northern Minnesota, northern Wisconsin, and Michigan, and at the east end of Lake Superior, the lower Keweenawan is represented by a conglomerate and sandstone of moderate thickness, none of the exposed measured section being more than 300 feet thick. These beds of sediments are, however, important as indicating that very generally for the Keweenawan the first deposits of the period were sedimentary and antedated the outbreak of regional igneous activity.

MIDDLE KEWEENAWAN.

The middle Keweenawan is the great epoch of combined igneous and aqueous activities. Thus there are two divisions of rocks—original igneous and derived sedimentary.

Igneous rocks.—The igneous rocks constitute a province of rather remarkable uniformity. The different kinds of igneous rocks and their relations are substantially the same in each of the important districts. From a chemical point of view the igneous rocks include basic, acidic, and intermediate varieties. However, the basic materials overwhelmingly dominate. The acidic rocks are important in quantity, and the intermediate rocks are subordinate. As to structure, each variety of rocks includes both intrusive and extrusive facies, so that the basic, acidic, and intermediate groups each have textures characteristic for plutonic and volcanic rocks.

The basic plutonic igneous rocks comprise gabbros, both olivinitic and nonolivinitic, diabases, olivinitic and nonolivinitic, and anorthosite. The surface varieties include melaphyres, porphyrites, and amygdaloids. The coarse-grained melaphyres have often been called dolerites, diabases, or ophites, depending upon their structure. The deep-seated phase of the acidic rocks is granite, augitic or hornblendic, and the extrusive phase is porphyry, quartziferous and nonquartziferous, and felsite. The most important intrusive phases of the intermediate rocks are described by Irving as augite syenites and orthoclase gabbros, and the extrusive varieties as porphyrites. Trap is used in its usual sense to cover both basic and intermediate varieties of rock.

The extrusive rocks are almost altogether a mass of lava beds, one piled upon another, the volcanic clastics being insignificant in quantity. The total volume of the extrusives is vast, but probably not so great as the volume of the intrusive rocks. The textures and structures exhibited by these ancient lavas are in all respects like those of modern lavas, although of course they have undergone extensive metasomatic changes. The basic lavas greatly predominate. The beds vary from those less than 2 feet in thickness to those 100 feet or more in thickness. The thin flows have a very moderate extent, and even the thicker flows have usually not been traced any great distance, although it is said of certain definite flows that they have been identified for distances varying from 10 to 30 miles. Groups of lava beds have been traced to great distances—up to a maximum of 150 miles. However, no group of lava beds has been traced through the entire Lake Superior region.

The acidic flows differ materially from the basic flows. In general they appear to have been much less fluid and therefore have a much shorter lateral extent in proportion to their thickness. In fact, a bunchy or lenticular form is characteristic of them. This is illustrated by Mounts Houghton and Bohemia, on Keweenaw Point. Amygdaloidal textures are not common with them, as in the basic lavas. A flowage structure, on the other hand, is much more frequent in them than in the basic lavas, and glassy textures are exceedingly common.

Chemically the intrusives include the basic, acidic, and intermediate varieties of rocks. Structurally the intrusive masses comprise every known form of that class of rocks with the exception of batholiths. There are great laccoliths, many large bosses, numerous and extensive sills, and very abundant dikes, from those of small size to those hundreds of feet across. Many of the dikes and sills beautifully show a columnar structure. In many of the earlier studies the sills were not separated from the lava flows. As to magnitude, the masses vary from the " St. Louis River gabbro " of Minnesota, which has an area of 2,400 square miles, to emanations so small as to be lost in the intruded rocks. It appears probable that the volume of the intrusives within the previously formed extrusive lavas and conglomerates is really greater than the volume of the lavas themselves.

The greatest of the intrusions of late Keweenawan time are basic. These are represented by the gabbro laccoliths of Minnesota and Wisconsin. The acidic masses are also sometimes large, but they are likely to occur in bosslike forms.

No general order of eruption for the Keweenawan lavas can be announced, but locally an order has been determined. Thus near the mouth of Montreal River, on Keweenaw Point, Hubbard finds that melaphyres have first been extruded, then porphyrites, then felsites, and following these the great period of basic activity.

Sedimentary rocks.—The sedimentary rocks are dominantly conglomerates and sandstones. Shales are subordinate. A light-red to dark-red color is very characteristic for the Keweenawan detritus interstratified with the lava beds. Among them gray sandstones are unknown. The conglomerates vary in coarseness from great bowlder conglomerates to fine conglomerates, and these grade into the sandstones, and the latter often into shales. All the sediments belonging to the division under consideration are interstratified with the lava beds. The detritus of the sandstones and conglomerates is dominantly derived from the Keweenawan igneous rocks themselves.

The detritus, comprising bowlders, pebbles, and grains of sand, being derived from the igneous rocks of the group, includes materials from all varieties of the basic, intermediate, and acidic rocks. The ease of recognizing the fragments of considerable size has led to a closer study of the conglomerates than of the sandstones and shales.

However, the detritus of the conglomerates and sandstones is largely, or even dominantly, from the acidic group of lavas, felsites, porphyries, and granites, and often also from the intermediate rock, augite syenite, even when the sedimentary beds are between basic lavas.

These sediments are regarded as largely terrestial deposits.

As to the extent of the sediments interstratified with the lavas, the same statements may be made as with reference to the lavas—none of them are regional. Indeed, the detrital beds between the lavas are usually extremely local; at least, as yet, they have for the most part not been traced any great distance. In proportion as these are thick they naturally have a greater lateral extent. The thickest of these formations, the great conglomerate of Keweenaw Point, which has a maximum thickness of 2,300 feet, has been traced more than 100 miles, and one of the comparatively thin conglomerates lying immediately under the greenstone of Keweenaw Point has been traced 50 miles. A given conglomerate bed may vary greatly along the strike in the proportion of the constituents from a given source; it frequently varies also in thickness and coarseness. When conglomerate beds thin they often run laterally into sandstones or shales, the coarser fragments failing altogether. Finally, a single sedimentary bed along the strike may be split into more than one bed by interleaved lavas.

As to the order of events for the volcanic epoch, it is to be strongly emphasized that no part of it was a time exclusively of igneous or of sedimentary action. While water-deposited sediments are thus characteristic of the entire middle Keweenawan, it is to be said that their mass is extremely subordinate for all except the upper part of this series. Thus in Minnesota, where the lower and middle portion of the middle division is exposed, Lawson estimates the sediments to be less than one-half of 1 per cent. On Keweenaw Point also, at the Eagle River and Portage Lake sections, in the major portions of the sections sediments are extremely subordinate. As the upper part of the division is reached, however, there is a change in the importance of the conglomerates. The interstratified beds of sandstone and conglomerate are rather numerous. Commonly they are of moderate thickness, but at the upper part of the series these conglomerates occasionally are of sufficient thickness to become important formations. By far the thickest of these sedimentary beds is the "Great conglomerate," which has a maximum thickness of more than 2,000 feet. Another important sedimentary bed of this later time is the so-called middle conglomerate of Keweenaw Point. After the volcanic period had been inaugurated and considerable masses of the

Keweenawan had been built up, the rising lava from the deep-seated reservoirs penetrated the earlier Keweenawan precisely as it did the series earlier than the Keweenawan. These intrusions continued throughout the major portion of middle Keweenawan time, and thus earlier intrusives are cut by later intrusives.

UPPER KEWEENAWAN.

The upper Keweenawan is confined to northern Wisconsin and Michigan, where it constitutes a great sedimentary group consisting of conglomerates, sandstones, and shales. It has been divided into three formations, from the base up: (1) The "Outer conglomerate," consisting mainly of conglomerate with red sandstone; (2) the Nonesuch formation, consisting of black shale and gray sandstone; and (3) the Freda sandstone, the main body of red sandstone. The "Outer conglomerate" has been traced for a distance of between 175 and 200 miles. Its thickness has been estimated at different places as varying from 350 feet to nearly 5,000 feet. The Nonesuch formation has been traced 125 miles. Its thickness varies from 125 to 500 feet. This formation, unlike the sandstones and conglomerates at lower horizons, contains a large and sometimes dominant amount of basic detritus. The Freda sandstone constitutes much the larger portion of the upper division of the Keweenawan. At Montreal River Irving estimates the thickness of this sandstone at 12,000 feet. This sandstone, like the Nonesuch formation, is very largely composed of basic detritus. In places it is nearly quartzless. Thus it is clear that its source is dominantly the basic igneous rocks and only subordinately the acidic igneous rocks of the Keweenawan. Also in places the pre-Cambrian rocks have contributed subordinate amounts of material.

STRUCTURE.

As was shown by Irving, the Keweenawan as a whole is a great synclinorium, the margin of which for the eastern half of Lake Superior closely corresponds with the shore, but which for the western half of the lake extends for a considerable distance inland. Subordinate to the greater syncline are other lesser synclines, such as the extensions of Chequamegon Bay, Fond du Lac Bay, and Nipigon Lake. The dips of the rocks are very variable, ranging from almost flat in the neighborhood of Thunder, Black, and Nipigon bays to angles of 60°, 70°, or even 80° north of the Gogebic district in Michigan and Wisconsin. In general the dips to the south on the north shore of Lake Superior are less steep than the dips to the north on the south shore. Also in any section the dips are steeper at the lower horizons than at the higher horizons. Correlative with the folding there is extensive faulting. The best known case of faulting occurs southeast of Keweenaw Point, but wherever close local studies have been made, as on the northwest part of Keweenaw Point, northern Wisconsin, and on Isle Royal and elsewhere, complicated and sometimes extensive faults have been shown to exist.

THICKNESS.

The maximum thickness of the Keweenawan was estimated by Irving at the Montreal River section to be 45,000 feet. Lane confirms this estimate in the Black River section. These figures are probably too large, since the apparent thickness may have been increased by faulting and the dips may in part have been initial.

The great quantity of material of the Keweenawan does not of necessity mark a period longer than, or perhaps even one as long as, the lower Huronian or upper Huronian, for the greater part of it is of igneous origin and doubtless accumulated rapidly. The lava flows in their extent and thickness are to be compared with the great volcanic plateaus of the Far West rather than with local volcanoes, such as Vesuvius, or the local volcanoes of the upper Huronian and lower Huronian.

COPPER DEPOSITS.

Keweenaw Point is especially noted as being the locality at which the valuable native copper deposits of the Keweenawan series are found. The copper ores occur (1) in sandstones and conglomerates interstratified with lava beds, (2) in the scoriaceous parts of amygdaloids, and (3) in veins cutting the igneous rocks. In all of these deposits the copper occurs both in the original openings and as replacements in the igneous and clastic rocks.

GENERAL STRUCTURE AND DISTRIBUTION OF LAKE SUPERIOR ROCKS.

For the region as a whole it is difficult to make a brief statement adequately covering the complex structure and distribution of the pre-Cambrian rocks, but consideration of a few general features may aid in fixing the reader's ideas of the general geology of the region. By mapping under one symbol all greenstones and under another symbol all granites, whether of Archean or of Algonkian age, the granite and greenstone areas may be easily remembered in their general distribution. By so doing also we avoid the necessity of drawing boundary lines between granite and greenstone of different ages in the parts of the Lake Superior region in which a separation has not been satisfactorily made. For stratigraphic purposes the granite and greenstone areas may be practically eliminated from consideration. There then remain principally, as the rocks with which we are primarily concerned in comprehending the general stratigraphy of the region, the pre-Cambrian sedimentary series with interbedded volcanics. These are grouped about the western half of Lake Superior. The west end of Lake Superior consists of an eastward-pitching synclinorium of Keweenawan rocks with gentle southerly dips on its north limb and fairly steep northerly dips on its south limb, the Keweenawan series there fringing the western half of the lake. The underlying rocks, the upper Huronian, may be considered also as taking part in this synclinorial structure and as having a distribution consonant with such structure—that is, bordering the outer edge of the Keewenawan areas. In detail the structure of the upper Huronian is far more complex than that of the Keweenawan series, and in Michigan, in the triangular area extending eastward from the Penokee-Gogebic district and fingering out in the Marquette, Crystal Falls, and Menominee districts, the upper Huronian appears in a series of rolls which apparently have no counterparts in the Keweenawan series. The lower and middle Huronian sediments occupy but limited areas as compared with the other Algonkian rocks. For the most part they are closely folded and have steep dips. Their strikes and dips give evidence that they were complexly folded before the beginning of the earth movements which resulted in the Lake Superior synclinorium. They accord in structure only in that the prevailing strike of bedding, folds, and cleavage is east-northeast, parallel to the axis of the Lake Superior syncline. The same is of course true of the Archean.

It has been possible to explain the major structure and distribution of the Algonkian rocks on the basis of folding. Faulting has been recognized in many places, and locally has been important. Recent study has tended to show that faulting has played a greater part than had been supposed, although still a subordinate part. A system of definitely recognizable strike and dip faults has been worked out in the Marquette district by Seaman, and the effect of these faults on the distribution and structure of the ore deposits has been noted in at least one of the mines. Presumably further work will show more of such features. In the Gogebic district important faults, both across and parallel to the iron-bearing formation, have been found to have an important bearing on the distribution and structure of the ore deposits. In the Mesabi range normal faulting, inferred but not observed during the preparation of the Geological Survey report on the Mesabi range,[a] has been found by further mining operations in the Biwabik mine. Strike faults of considerable magnitude also occur in the Animikie iron range east of Thunder Bay.

As a result of the closer folding of the lower series in the region as a whole, as compared with the higher ones, and as a result also of the intrusion into the lower series of larger masses of deep-seated, igneous

[a] Mon. U. S. Geol. Survey, vol. 43, 1903.

rocks than into the higher series, the lower series shows in general more profound metamorphism than the upper series.

FOSSILS IN LAKE SUPERIOR PRE-CAMBRIAN.

The discovery of fossils has been reported from time to time in the pre-Cambrian formations in various parts of the Lake Superior region, but in no case has the discovery been verified by subsequent study. Presumptive evidence of life is afforded by the presence of carbonaceous slates and of limestone, presumably developed at least in part through organic agencies. Also the existence of cleanly sorted sediments in the Algonkian points to complete decomposition in preexisting land areas, a process usually requiring organic agencies.

UNCONFORMITY BENEATH THE CAMBRIAN.

In discussing the relation between the Cambrian and Keweenawan, distinction must be made between the lower-middle Keweenawan and the upper Keweenawan. It is agreed by all that there is a profound unconformity between the lower-middle Keweenawan and the Cambrian. The former beds dip steeply; the latter are flat-lying. Actual unconformable contacts may be observed in the St. Croix area and in the area southeast of Keweenaw Point. But the dips of the Keweenawan become progressively lower in the upper part of the series, and the dip of the upper beds is so low as to suggest possible gradation into the Cambrian sandstone. It is the contention of Seaman, Lane, and others that such gradation exists. The evidence favoring it is as follows:

(1) At the mouth of Montreal River the dip of the Keweenawan beds is 80° toward the lake; half a mile to the west, at the mouth of Oronto River, it is 52° in the same direction; and the next exposures 5 miles to the west, mapped as Cambrian by Irving, dip as high as 15° in the same direction. Farther to the west, toward Ashland, are the flat-lying Cambrian sandstones. Fossils have not been found in the Cambrian near the contact.

(2) Lithologically the upper Keweenawan and the Cambrian are similar in their feldspathic content, in their reddish color, in containing shale bands, and in their degree of induration, though the Cambrian as a whole may be somewhat more quartzose and less shaly and feldspathic than the Keweenawan.

(3) No contacts between the Cambrian and upper Keweenawan have been observed where not complicated by fault relations.

(4) The Cambrian sandstone and the upper Keweenawan were naturally regarded as the same by some of the earlier writers and the burden of proof rests on one who would separate them. In fact there has always been doubt as to the assignment of certain exposures to one or the other series.

(5) The lack of igneous rocks in the Cambrian is not regarded as good evidence for unconformity, because igneous rocks are also lacking from the upper part of the Keweenawan.

(6) The lack of fossils in the lower series is to be explained because of the character of the sediments.

(7) It is improbable that a very considerable interval should elapse with no deposition in the Lake Superior basin, and that deposition should begin again with so little evidence of erosion or valley trenching of the upper Keweenawan.

(8) If the Animikie group is ever found to be the equivalent of the Belt series of British Columbia, as is thought possible, this would make more probable the Cambrian age of the Keweenawan lying above the Animikie, in view of the fact that in British Columbia the Belt series apparently grades up into the Cambrian.

Against this evidence of possible conformity and favoring the view here held that the Cambrian lies unconformably above the upper Keweenawan are the following facts:

(1) The Cambrian is fossiliferous, but the Keweenawan is not.

(2) The Cambrian contrasts with the Keweenawan in lacking volcanism and deformation. So far as they share in deformation, it is through faulting which may have taken place as late as the Cretaceous.

(3) The Cambrian rests upon a peneplain of continental extent, over which the Paleozoic sea swept and deposited Paleozoic sediments, with overlap relations to the pre-Cambrian rocks. This sea did not reach the Lake Superior country until upper Cambrian time, and parts of Canada were not reached until Ordovician time. If the Keweenawan is Cambrian it constitutes a local marked variation from the general uniform conditions of overlap. The upper Keweenawan sediments rest on a plane which cuts the pre-Cambrian peneplain at a considerable angle, as is well shown on Keweenaw Point.

(4) The similarity of lithology and accordance of structure between the Keweenawan and Cambrian are the natural sequence of transgression of a sea over flat-lying sediments. The conditions are not different from those that would prevail if the ocean were to transgress to-day from the Gulf of Mexico across the flat-lying and little-consolidated Paleozoic sediments of the upper Mississippi Valley. It would be extremely difficult to prove the unconformity in any limited area, especially where exposures are not numerous. In this connection it should be remarked that the low dips of the Cambrian strata up to 15°, as at Ashland, are no evidence against this hypothesis, for the highest dips which the Cambrian has are not greater than may occur with similar sediments along a steep shore. Therefore the dips of the Cambrian sandstone may be initial and consequently may afford no evidence that deformation has taken place since their deposition.

If it be granted that the Keweenawan and Cambrian are unconformable throughout, there may still arise the question whether the Keweenawan deposition was not going on in the isolated Lake Superior basin both before and during lower and middle Cambrian time, while the Paleozoic sea was transgressing from the south—in other words, whether the unconformity in question may not represent an inter-Cambrian interval rather than a pre-Cambrian interval. It has seemed to us, as it has to Irving, Chamberlin, and others who have had the facts in hand, that the unconformity is probably too great for an inter-Cambrian unconformity, but no decisive evidence is yet at hand to close the question finally.

We would emphasize the facts that the Keweenawan represents conditions of deposition radically different from those of the Cambrian and that evidence of unconformity is strong for part of the series, but we recognize the possibility that the deposition of the upper part of the Keweenawan may have continued into lower and middle Cambrian time.

UNCONFORMITY BENEATH THE KEWEENAWAN.

Evidence of the existence of an unconformity at the base of the Keweenawan is for the most part not conspicuous, because of the slight divergence in strike and dip between the Keweenawan beds and the underlying upper Huronian rocks, because of the faulting which has obscured the relations in Michigan, Wisconsin, and part of Minnesota, and because of the fact that the bottom member of the series in parts of Minnesota and Wisconsin is intrusive gabbro. The broad field distribution of the Keweenawan series affords excellent evidence of its unconformity on the underlying series, for it comes in contact now with one and now with another of the underlying series. The most direct evidence of unconformity may be seen in the Port Arthur district on the northwest shore of Lake Superior, where the base of the Keweenawan, consisting of coarse conglomerates, sandstones, and limestones, rests against the eroded edges of the gently tilted slates or the iron formation of the Animikie group and highly tilted lower-middle Huronian graywackes and granite. In the central part of the Gogebic district the basal member of the series, usually a gabbro but locally conglomerate, rests against the upper Huronian iron formation, while in the east and west ends of the district it rests against upper Huronian slate. In the Mesabi district also the gabbro at the base of the Keweenawan laps diagonally across the three members of the upper Huronian onto the Giants Range granite. It might be argued, because of the intrusive nature of the gabbro, that its relations to the underlying series would afford no sound evidence of unconformity at the base of the Keweenawan. It is thought, however, that the surface of contact is essentially an erosion surface because of its low angle to the bedding of the upper Huronian rocks, otherwise it would be necessary to assume that the gabbro had intruded itself along a plane gently inclined to the Huronian series, in which case there ought to be Animikie rocks both above and below the gabbro.

UNCONFORMITY BENEATH THE UPPER HURONIAN, OR ANIMIKIE.

The unconformity beneath the upper Huronian, or Animikie, has been recognized generally throughout the Lake Superior region where Animikie rocks are exposed. The evidence is especially striking in the Thunder Bay and adjacent districts on the northwest shore of Lake Superior, where gently tilted Animikie sediments rest with basal conglomerates upon highly tilted and eroded rocks of lower-middle Huronian, Keewatin, and Laurentian age. The difference in amount of deformation and consequent metamorphism between the Animikie and the underlying rocks is striking. A characteristic feature of the underlying sediments is a steeply inclined secondary cleavage, which is absent in the Animikie. Scarcely less obvious are the relations of the Animikie to the underlying rocks in northeastern Minnesota, where many actual contacts as well as the broad field relations point to the existence of the unconformity.

On the south shore of Lake Superior the upper Huronian is more highly inclined, but otherwise its relations to the underlying lower and middle Huronian and Archean rocks are fully as clear as on the north shore. These relations are best seen in the Marquette district. Here at many points at the bottom of the upper Huronian is a basal conglomerate, the detritus of which is mainly derived from the underlying formations in direct contact with it. Also at some of these points there is a marked discordance between the bedding of the two formations. This unconformable relation is especially clear between the Negaunee formation, constituting the upper member of the middle Huronian, and the Goodrich quartzite, the lowest formation of the upper Huronian. In the Gogebic district the Animikie is locally in contact with the cherty limestones of the lower Huronian, and in other places with the Archean. The dominant fragments of the basal conglomerate vary accordingly. While the unconformity at the base of the upper Huronian is clear, at various places in Michigan and Wisconsin the upper Huronian has been so closely folded that its general distribution does not give decisive evidence of its unconformity on the underlying rocks.

The evenness of the contact of the Animikie group on the underlying group on the north shore and in the Gogebic district on the south shore indicates a truncation of the underlying group for at least the western half of the Lake Superior region amounting almost to base-leveling. The frequent thinness of the conglomerates at the base of the Animikie and the usually small sizes of the pebbles also are in accord with the supposition of base-leveling in the preexisting land areas.

In the past the Canadian geologists, observing the unconformity at the base of the upper Huronian, principally on the north shore, have been so impressed with its magnitude and the striking differences in deformation and metamorphism of the rocks above and below that they have refused to regard it as an inter-Huronian unconformity, and have maintained that it separates the Cambrian above (in which they included Keweenawan and Animikie rocks) from the Huronian below. Their emphasis on this unconformity is not surprising when we remember that on the Canadian shore the Animikie group rests on steeply tilted and highly metamorphosed rocks of Archean age and only locally on rocks of lower-middle Huronian age. On the south shore the unconformity is still a great one, but not so striking as that on the north shore, for the Animikie largely rests upon middle and lower Huronian rocks not contrasting so markedly in lithology and structure with the Animikie as do the Archean rocks.

Farther south, in the Crystal Falls, Felch, Iron River, and Menominee districts, the upper Huronian appears to be nearly conformable, structurally, with underlying sediments which are similar lithologically to and have been correlated with the lower Huronian of the Marquette district. The significance of this relation is discussed on page 362.

UNCONFORMITY BENEATH THE AJIBIK QUARTZITE (MIDDLE HURONIAN).

Seaman has shown the existence of an unconformity at the base of the Ajibik quartzite in the Marquette district, evinced by basal conglomerates and truncation of the underlying series. The Ajibik quartzite is found in contact with each of the three members of the sedimentary series below and with the Keewatin, indicating that the erosion plane has cut completely across the underlying series. The Ajibik quartzite and younger rocks are also slightly less metamorphosed than those beneath the unconformity.

UNCONFORMITY BENEATH THE HURONIAN SERIES.

The unconformity at the base of the Huronian series is more obscure than higher ones, and has been less widely recognized. Failure to recognize this break has been due to the high degree of metamorphism, which has often obliterated evidence of unconformity and given rocks parallel secondary structures on both sides of it; to the similar lithological character shown by the metamorphosed sediments and the underlying phases of the Archean, particularly where these are greenstones and green schists of the Keewatin, and, finally, to the fact that the banded and contorted gneiss, which is prominent in the basal complex, does not differ greatly in lithological character from some areas of later granite gneiss which have intruded the clastics. This later granite gneiss is, however, usually somewhat nearer the normal form of an eruptive rock, not having suffered so many vicissitudes in its briefer history. Those whose attention has been mainly directed to the contact phenomena of the intrusive granite gneisses have generally refused to believe in an earlier granite gneiss, although recognizing, at least in some cases, that the lowest detrital rocks bear numerous fragments of a granite gneiss. On the other hand, those whose attention has been directed to the unconformities, as indicated by basal contacts and other phenomena, between the basal complex and the clastic series have sometimes been disinclined to believe in the existence of important areas of granite gneiss which are intrusives later than the clastic series. Generally, in the districts which have been studied by individual writers, the phenomena of the one class are conspicuous while those of the other class are unimportant or perhaps lacking altogether. Naturally this has engendered an inclination in each observer to conclude that the relations which have strongly impressed him are true of the entire Lake Superior region.

Notwithstanding the above considerations, conclusive evidence of the existence of a profound unconformity between the lower Huronian and the underlying rocks is now known in many parts of the Lake Superior region. Some of the best evidence, and the first to be worked out, appears in the Marquette district. Here basal conglomerates of the lower Huronian are found in contact with all the members of the Keewatin and Laurentian divisions of the Archean. Commonly parallel schistosity has been developed along the contact, in places entirely destroying the conglomerates and giving the appearance of a gradational zone. However, there is usually a considerable contrast between the massive and schistose igneous rocks on one side of the contact and the clearly recognizable sedimentaries on the other. In places also, as near the Carp River and south of Marquette, the cleavage of the underlying Keewatin stands at a high angle to the surface of contact with the Huronian. Dikes are found penetrating the Archean rocks which do not enter the Huronian rocks above. Metamorphism and deformation in general are much more pronounced in the Archean rocks than in the Huronian. In short, there appear all of the evidences usually cited to prove the existence of unconformity.

In the Crystal Falls and Menominee districts the basal conglomerates of the Sturgeon quartzite at the base of the Huronian series, resting against members of both the Keewatin and the Laurentian series, present conclusive evidence of the existence of a great pre-Huronian unconformity in these districts.

In the Gogebic district an unconformity beneath the cherty limestone mapped by Irving and Van Hise as the bottom of the Huronian series, was inferred from the general field distribution and the contrast in lithology, deformation, and metamorphism. This belt of cherty limestone was found to extend with uniform strike across various highly metamorphosed and deformed members of both the Laurentian and the Keewatin series. They found no actual contacts. Subsequently Seaman and Sutton found quartzite and basal conglomerate beneath the limestone, resting upon steeply tilted schistose Keewatin rocks, presenting proof diagrammatic in its clearness.

In the Vermilion district of Minnesota the great Stuntz and Ogishke conglomerates at the base of the Huronian series are found to rest against all the members of the Laurentian and Keewatin of this district. Here again the general difference in deformation, metamorphism, and intrusion by igneous rocks exhibited by rocks above and below the unconformity is striking. But locally the fragmental rocks of the lower-middle Huronian can scarcely be distinguished from the igneous rocks, acidic or basic, from which they have been derived. There is an especial difficulty in distinguishing some of the greenstone conglomerates of the lower-middle Huronian from the volcanic breccias and tuffs of the Keewatin. Indeed, the possibility must be distinctly recognized that there are localities in the Vermilion district where there may have been continuous sedimentation from the Keewatin to the Huronian, volcanic action dying out toward the end of the Keewatin and normal aqueous sedimentation becoming more important in the lower-middle Huronian.

In the Mesabi district may be seen similar evidence of unconformity between the lower-middle Huronian and the Keewatin. The Laurentian is present in but very small quantity.

In the Rainy Lake district conglomerates mapped as Keewatin are believed to represent the base of the Huronian series. These are found in contact with Laurentian granite and Keewatin green schists. In the latter case both are highly metamorphosed, and parallel schistosity has been developed, but there is still difference in lithology and texture, and an unconformity was not doubted when the contact was observed by the members of the joint committee of Canadian and United States geologists.

In the Steep Rock Lake area Pumpelly and Smyth described the unconformable contact of the Huronian rocks upon Laurentian granites.

In the Thunder Bay district schistose conglomerates are found in contact with Keewatin green schists in the Loon Lake region.

In the region about Michipicoten Harbor the Dore conglomerate, believed to represent the base of the Huronian series, may be found resting against Keewatin green schists, with differences in lithology, deformation, metamorphism, and amount of igneous intrusion.

Notwithstanding the local obliteration of the pre-Huronian unconformity, the evidence is conclusive that here is a break of the first magnitude at the base of the lowest Huronian group. Below it is a series of Laurentian and Keewatin rocks of great lithological complexity, very largely igneous, but in small part sedimentary, highly crystalline throughout, with exceedingly common schistose structures. Above the unconformity the Huronian rocks present comparatively simple lithology, clear-cut sedimentary origin, and usually less deformation and metamorphism than in the Laurentian and Keewatin rocks. Of greatest significance is the great predominance of igneous rocks below the unconformity and of sedimentary rocks above, representing fundamental changes of physical conditions. It is not at all unlikely that the sedimentary portion of the Archean, now known in small patches, will be found to be more extensive, but the Archean as a whole is sufficiently well known to preclude the possibility that anything more than a small percentage of it will be shown to be of sedimentary origin. For the rocks below the unconformity the term basement complex is highly appropriate. It is really the undivided complex below the stratified rocks of the geological column for which the term Archean was designed.

CORRELATION.

Correlation of Lake Superior rocks with one another.—A detailed correlation of the formations of the various districts of the Lake Superior region has been summarized in the table on pages 328–329. The terms used are the ones adopted by the joint committee of Canadian and United States geologists, with the addition of the terms Archean and Algonkian, expressing the writers' view of the grouping of the series recognized by the committee. The principal lines of evidence upon which this correlation is based are sketched below. To avoid confusion, the various views which have been presented in the past and the variety of names used will not be discussed. These are taken up on pages 367 et seq.

The four great unconformities—at the base of the Cambrian, at the base of the upper Huronian, at the base of the Ajibik quartzite of the middle Huronian, and at the base of the Huronian series—serve as a basis for the major grouping of the pre-Cambrian rocks and their correlation throughout the region. If all of these unconformities could be discovered in all parts of the region they would be sufficient for a complete correlation. As they have not been recognized so widely, it is necessary to rely on a comparison of the lithology and successions of the groups of the different districts and their relative positions with reference to the unconformities. Indeed, likenesses of lithology, successions, metamorphism, structure, and other relations of the groups are often the basis for the correlation of the unconformities. Consideration of all the known factors taken together affords a satisfactory basis for correlation.

The Keweenawan series is recognized by all as a great structural unit occupying considerable parts of the north, northwest, and southwest shores of Lake Superior. The same may be said of the Animikie or upper Huronian group. In both we have well-marked, easily ascertainable horizons, extending well over the Lake Superior region. They are separated from each other by an unconformity, and unconformities of great magnitude separate them from series both above and below. The unconformity beneath the Animikie is so striking and widespread that it can scarcely be mistaken. The extent, lithological unity, and relations to conspicuous unconformities make the Keweenawan and Animikie rocks satisfactory horizons from which to carry down correlation of the other less extensive, separated, and lithologically diverse groups of the Lake Superior region. The Keewatin and Laurentian rocks making up the basement complex also present sufficient lithological and structural uniformity to make them useful in correlation in connection with the overlying unconformity. It is not always possible to use them alone, however, because of the difficulty of distinguishing Laurentian granites and gneisses from Huronian granites and gneisses, or of distinguishing some of the Keewatin volcanics from those of the higher horizons.

Beginning northeast of Lake Superior we shall consider in turn the regions north, west, and south of the lake.

The rocks of the Michipicoten district are believed by all to be unconformably beneath the Animikie, although the Animikie is not found near the lake shore in this area. The reasons for this are the steep attitude and metamorphosed character of the Michipicoten rocks as compared with the flat-lying, little-metamorphosed rocks both to the west of Nipigon Bay and in the Sudbury basin to the east. The lower rocks of the Michipicoten district consist of greenstones, green schists, iron formation, and slate, typical in all their aspects to the Keewatin of the rest of the region. The upper formation, the Dore conglomerate, rests upon the Keewatin and, being beneath the Animikie, is called lower-middle Huronian. The granite is regarded by Coleman and Willmott as intrusive into the Huronian. It is certain that some of it is intrusive into the lower-middle Huronian sediments, but that other parts of it antedate the Huronian sediments is extremely probably because of the great quantities of granite fragments similar to those of the Laurentian in the Dore conglomerate at the base of the Huronian series.

Westward from Port Arthur, along the international boundary to Gunflint Lake, the Animikie rocks are found to rest unconformably upon the principal sedimentary rocks of the Vermilion district, the Knife Lake slate, Ogishke conglomerate, and Stuntz conglomerate, similar to the Dore conglomerate of the Michipicoten district. Beneath them is a complex of greenstones, green schists, and iron formation, similar in all respects to that beneath the Dore conglomerate of the Michipicoten district. These are typical Keewatin. The conglomerate and slate series above is accordingly placed in the lower-middle Huronian. Granites intrusive into the Keewatin are classed as Laurentian.

West-southwest from Gunflint Lake, in the Mesabi district, the Animikie group is found to contain the great iron-bearing member of the Mesabi iron range. Here also the Animikie overlies a graywacke and slate group intruded by granite, similar in all respects to the group underlying the Animikie in the Vermilion district. It is accordingly assigned to the lower-middle Huronian. Beneath this lower-middle Huronian there is a complex of greenstones and green schists showing characters identical with those exhibited in the Keewatin of the Vermilion district, and hence it is so classed.

In central Minnesota a considerable body of sediments, typically exposed at Carlton and Cloquet, has been referred to the upper Huronian because of their lithological and structural similarity to the upper Huronian of the Mesabi district, and because they have a position which would indicate them to be part of the southern margin of the syncline of Animikie rocks supposed to extend south from the Mesabi district.

The similarity in lithology, succession, and structure of the Mesabi iron-bearing strata with those of the Gogebic district, and the fact that the Mesabi strata dip gently to the south and the Gogebic rather steeply to the north, conforming to the general synclinal structure of the Lake Superior basin, leave little doubt that the Animikie or upper Huronian extends to the south shore. A sketch map showing a supposed connection of the Mesabi and Gogebic districts on the hypothesis of synclinal structure was given in Monograph XLIII, published in 1903. Since that time exploration and development have shown the existence of an iron formation, probably of upper Huronian age, in the Cuyuna range on the south side of this hypothetical syncline.

Beneath the upper Huronian of the Gogebic district, with profound unconformity, is a limestone and a quartzite formation representing the remnant of a lower group. Unconformably beneath this in turn is a complex of greenstones and green schists, undoubtedly Keewatin, and granites of Laurentian age. The limestone and quartzite are correlated with the lower Huronian of the Marquette district on the basis of lithology, succession, and relations.

The predominating member of the upper Huronian, slate, appears in many exposures eastward from the Gogebic district through the great triangular area connecting with the Crystal Falls, Marquette, and Menominee districts to the east. There is little room for doubt that the upper slate series in each of these districts is directly continuous with the slate of the upper Huronian of the Gogebic district.

In the Marquette district, beneath the upper predominantly slaty group, are two unconformable sedimentary groups formerly considered a unit. These may be called for convenience in discussion the middle and lower Huronian. As it has already been noted that the Marquette district is the only district in which this division of the sedimentary rocks beneath the upper Huronian has been made, the lower and middle groups of this district may for the present be correlated with the undivided lower Huronian of other parts of the Lake Superior region. Beneath the Huronian series is a complex of greenstones and green schists, of typical Keewatin aspect, bearing a small amount of iron formation and acidic igneous rocks characteristic of the Laurentian.

In the Crystal Falls district lithological representatives of the middle and lower Huronian appear beneath the upper Huronian and may be correlated in the same manner as in the Marquette district.

In the Menominee district the upper Huronian again appears, connected with the Animikie of the Gogebic district by isolated exposures. Beneath this, unconformably, is a sedimentary group lithologically similar to and probably to be correlated with the lower Huronian of the Marquette district.

In the Iron River district upper Huronian iron-bearing slates, similar in all respects to those in the Menominee district and probably continuous with them, are underlain by dolomite and quartzite which may be correlated with the lower Huronian in the Menominee district. This lower group rests upon a basement of green schist and granite connecting directly with the Archean of the Menominee district.

In the Crystal Falls, Felch, Menominee, and Iron River districts the upper Huronian is nearly conformable structurally with the rocks below, a relation contrasting strongly with that between the upper Huronian and underlying groups in the Marquette district. The significance of this relation is given on page 362.

Beneath the Huronian series of the Menominee, Crystal Falls, and Iron River districts is again a complex of greenstones and green schists, the Keewatin, and acidic igneous rocks, the Laurentian. Certain of these greenstones have volcanic textures and are similar to greenstones and green schists of the Crystal Falls district which have been mapped as Huronian.

Correlation of Lake Superior rocks with original Huronian rocks on north shore of Lake Huron.—In the Huronian of the original Huronian district there are two unconformable sedimentary groups. These two sedimentary groups are believed to underlie unconformably the Animikie group. Nowhere are Animikie rocks in direct contact with original Huronian rocks as mapped in detail by Logan and Murray, but north of Sudbury such rocks, showing far less folding and metamorphism than the original Huronian series, do rest unconformably upon rocks closely similar lithologically to the original Huronian rocks.

The Sudbury rocks are a part of Logan's Huronian series. Therefore the Huronian series of the north shore of Lake Huron is divided into three unconformable units, upper Huronian, middle Huronian, and lower Huronian, the two lower groups appearing in the area on the north shore mapped in detail by Logan and the upper one a little to the northeast in the Sudbury district. The original Huronian rocks are known, moreover, to rest unconformably upon Keewatin green schists and Laurentian granites. In their unconformable position beneath the Animikie and above the Keewatin and Laurentian, in their divisibility into two groups by an unconformity, in lithology, and in succession they are similar to the lower and middle Huronian of the Marquette district.

General correlation.—The Keweenawan and all the underlying rocks are assigned to the pre-Cambrian because of the magnitude of the unconformity between the Potsdam sandstone and middle Keweenawan, because of the importance of volcanism in the Keweenawan and its complete absence in the Cambrian, because of the absence of fossils in the Keweenawan, and finally because the broad relations of the Paleozoic to the underlying rocks over North America point to a continuous overlap from easterly, westerly, and southwesterly directions, with the result that over a large area in the north-central portion of the continent upper Cambrian or Ordovician rocks were deposited directly upon the pre-Cambrian. If the Keweenawan is really Cambrian we should have here a middle or lower Cambrian series of enormous thickness but limited area, indicating radical departure from the general conditions of overlap shown by the continent as a whole. The joint committee report placed the Keweenawan in the pre-Cambrian, but Lane, one of the signers, dissented on this point.

The Keweenawan and Huronian rocks are together placed in the Algonkian, using this term to cover the sedimentary and related igneous rocks beneath the Cambrian and above a crystalline basal complex. The joint committee made no recommendation on this point. It is constantly necessary, both in description and in mapping, to refer collectively to the pre-Cambrian sedimentary rocks of the Lake Superior region to which stratigraphic methods may be applied, and to discriminate them broadly from the intricate complex of crystalline rocks of the Keewatin and Laurentian. The term Algonkian meets this need. Its use further implies emphasis on the unconformity between the sedimentary series and the basement complex, an unconformity which in the Lake Superior country is of fundamental importance. Finally, it makes possible a broad correlation of the Lake Superior pre-Cambrian sedimentary series above a crystalline basement complex with pre-Cambrian sedimentary series elsewhere in North America and other parts of the world without commitment as to correlation of individual formations or groups.

The term Archean is used to cover the Keewatin and Laurentian rocks of the basement complex. The same need is felt here for a collective term to express local Lake Superior conditions as in the case of the Algonkian; and it is even more necessary for purposes of correlation with other districts, for nowhere is it possible to correlate single formations or groups belonging to the basement complex for widely separated areas.

The correlation of the subdivisions of the Algonkian in different parts of the Lake Superior region is more difficult than the correlation of the Algonkian system as a whole. It involves consideration of varying conditions of deposition in the different parts of the district. The Keweenawan series constitutes essentially a continuous unit involving no difficulty in correlation as a whole. The Huronian rocks were deposited under different conditions in the following three subprovinces: (1) On the north shore the so-called lower-middle Huronian is thought to be probably in part a subaerial sediment. Coleman finds what he regards as adequate evidence of glacial origin in the Cobalt district. The lower Huronian occupies a position unconformably beneath the upper Huronian and unconformably above the Archean, a position occupied jointly by the lower and middle Huronian of the south shore. Our exact knowledge would be better expressed by calling this group on the north shore the lower-middle Huronian, but as the term lower Huronian is used so generally on the maps of this territory, it is thought that the use of the term lower Huronian will perhaps make less confusion than the introduction of the term lower-middle Huronian.

(2) In the belt running from the Gogebic district eastward to the north shore of Lake Huron there are two mutually unconformable sedimentary groups, both unconformably beneath the upper Huronian and unconformably above the Archean. These have been called the middle Huronian and lower Huronian. These rocks are well-assorted, water-deposited sediments, indicating proximity of shore lines.

(3) To the south of the Marquette belt of the Huronian, in the Crystal Falls, Felch, Menominee, and Iron River districts, the upper Huronian is underlain by formations lithologically similar to the lower Huronian of the Marquette district, but with slight evidence of unconformity.

The question therefore arises as to the explanation of this difference. It seems probable that the Marquette district was near a shore line during Huronian time. During this period there were two episodes of orogenic movement with uplift and subsidence, so that the Huronian series is divided into three unconformable groups. Farther to the south, in the Crystal Falls, Felch, Menominee, and Iron River areas, if such movements occurred, they were less strongly marked, and thus the different formations appear to be in conformity. Whether or not there were interruptions in the sedimentation is difficult to determine, but it should be remembered that the absence of positive evidence of an unconformity does not prove that the unconformity does not exist. While it is uncertain how far south the unconformities found in the Marquette and Gogebic districts extended, we have little difficulty in correlating the formations on the basis of succession of sediments of like kind and the continuity of the upper Huronian.

The criteria for discriminating subaqueous and subaerial deposition will not be discussed here in detail, but the essential evidence may be noted. Favoring the subaerial deposition of many of the Keweenawan sediments are the red color of the sands, the local banding of purple, red, and yellow colors, lack of assortment, mud cracks, ripple marks characteristic of streams rather than shores, and interlamination with surface igneous rocks having typical subaerial textures in contrast with textures developed in igneous rocks of the Huronian below. The subaqueous character of most of the Huronian sediments of the south shore is shown by their clean assortment, their green rather than red colors (indicating presence of ferrous iron), their abundant ripple marks of the kind characteristic of shore action, and their association with basalts showing pillow or ellipsoidal structure, which in many parts of the world has been ascribed to submarine extrusion.

SECTION 7. HISTORY OF DEVELOPMENT OF KNOWLEDGE OF LAKE SUPERIOR REGION.

LAKE SUPERIOR SANDSTONE.

The horizontal red sandstone of Lake Superior was recognized as the most extensive formation of the lake by the earliest geological voyagers, and in what follows this formation will be called the Lake Superior sandstone. The early travelers, Schoolcraft, Bigsby, and Bayfield, regarded it as the "Old Red sandstone," although Bayfield later considered it to probably underlie the fossiliferous red sandstone of St. Marys River. It was placed by Jackson, Marcou, and for a long time by Bell, as the "New Red sandstone." Very early others, including Dawson (Sir William), Foster, Houghton, Logan, Owen, Whitney, and Rogers, regarded the sandstone as "Lower Silurian" or Potsdam. In 1873 Rominger finally demonstrated what Houghton had long before stated, that the horizontal sandstone is directly overlain by the "Calciferous" formation. The sandstone was therefore placed as Potsdam, which position it has held since that time without dispute by anyone acquainted with the region.

It was very early seen that the horizontal sandstone is newer than the granites and slates of Lake Superior, which occupy a lower position than the Keweenawan. Schoolcraft saw, as early as 1821, the unconformity between the granite and the sandstone at Granite Point, and between the latter and the slates on St. Louis River at the head of Lake Superior. Bayfield recognized this unconformity in 1829, saying that the many instances of the conjunction of the sandstone and the granite proved that the sandstone was deposited after the granite occupied its present position. Rogers saw the same relations between the sandstone and the slates of Chocolate and Carp rivers, although at first he regarded the latter as "Primal." Owen, in 1847, described like unconformable relations between the horizontal sandstone referred to the Potsdam and the crystalline rocks in northern Wisconsin. Norwood, in 1847, again saw the unconformity between the Lake Superior sandstone and the slates of St. Louis River at Fond du Lac, described by Schoolcraft many years before. Foster, in 1848, saw the same unconformable relations between the sandstones and the slates at L'Anse. Since these early discoveries of the relations between the sandstone and the crystalline rocks were announced they have been confirmed at these original localities and at numerous other localities by many observers.

As to the relations of the Lake Superior sandstone with the sandstones interstratified with the trappean rocks, i. e., the Keweenawan, there has been the greatest diversity of opinion, and the question is one on which there is not yet entire unanimity, although the weight of the evidence is so strongly in favor of the inferior position of the Keweenawan series that this conclusion is rejected by but few geologists.

Bayfield, Bigsby, Burt, Rogers, Schoolcraft, and Whittlesey made no distinction between the Lake Superior and Keweenawan sandstones, apparently not recognizing that there was any question of their not being equivalent. Jackson, followed by Bell, for many years apparently regarded the Keweenawan sandstones as later than the Lake Superior sandstone. Jackson places the former as "New Red," and states that the sandstone of the Pictured Rocks may not be of the same age. Bell at first thought the Keweenawan Permian or Triassic, while cognizant of the fact that the Lake Superior sandstone is older than the Triassic, but recently this writer places the sandstone as probably unconformably above the Keweenawan. Foster, Wadsworth, Whitney, Winchell (N. H.), Lane, and Seaman, after comparisons and studies of the problem, have maintained that the Lake Superior and Keweenawan sandstones belong to the same series. Agassiz, Brooks, Chamberlin, Dawson, Houghton, Irving, Logan, Macfarlane, Bell, Owen, Pumpelly, Rominger, Selwyn, Strong, Sweet, and Wooster have held as their latest view that the Keweenawan series is older than the Lake Superior sandstone. Agassiz at first regarded all the sandstones of the same age, but afterward came to the conclusion that the sandstone was deposited against the upturned Keweenawan series. Agassiz, Brooks, Chamberlin, Dawson, Irving, Owen, Pumpelly, Rominger, Strong, Sweet, Wooster, and Hall maintain a great unconformity between the two. Macfarlane held that there was a doubtful unconformity between the Keweenawan series and the Lake Superior sandstone, the former occupying an inferior position. Houghton's, Logan's, and Selwyn's position is that the Keweenawan series is a downward extension of the Lake Superior red sandstone. The latter is regarded by Logan as probably Chazy, and the Keweenawan therefore "Calciferous" or Potsdam. Selwyn and Bell now place the Keweenawan as Cambrian.

The relations of the horizontal sandstone in northern Wisconsin to the melaphyres and traps regarded as Keweenawan have been described by all observers to be those of unconformity, the horizontal sandstone resting upon the upturned edges of the Keweenawan series. The only point of difference has been whether this sandstone is Potsdam or not. It is so regarded by the Wisconsin geologists and by Owen, but is by N. H. Winchell called "St. Croix" and placed above the Potsdam. No one doubts that it belongs near the base of the northwestern Paleozoics. The extensive area of horizontal sandstone about Agogebic Lake, between the two highly tilted trap ranges, was long ago cited by Brooks and Pumpelly as evidence that the Lake Superior sandstone is far later in age, it being found not distant from the highly tilted Keweenawan eruptives.

The controversy has been most extended as to the relations of the two series on Keweenaw Point. A part of what has been regarded as the Lake Superior sandstone, adjacent to the trap range, has been shown by Wadsworth to belong with the Keweenawan series, and just where at certain places the Lake Superior sandstone begins and the Keweenawan series ends is even yet a debatable question, because by all it is now agreed that near this contact is an ancient fault of great magnitude, along which post-Potsdam slipping has taken place.

The latest work is by Lane and Seaman, who conclude that the neo-Cambrian or Potsdam or Lake Superior sandstone includes (1) the sandstones west of the Copper range, to which the new term Freda sandstone is applied; (2) the sandstones east of the Copper range, to which the term Jacobsville is applied, and (3) the sandstones in the bluffs back of Munising, to which the term Munising sandstone is applied. The relations of the Freda sandstone to the Lake Superior sandstone are uncertain, but they are regarded as probably one formation. The Keweenawan series is regarded as representing the lower and middle Cambrian and not the upper part of the pre-Cambrian section. They are described as Cambrian beds disturbed by coeval volcanic activity and faulting, and seem comparable with inter-Keweenawan phenomena, while the Lake Superior sandstone and the upper Keweenawan appear closely associated, not merely lithologically but stratigraphically.

CHARACTER OF THE KEWEENAWAN SERIES.

Of the forms of the word proposed for this series, Keweenawian, Keweenian, and Keweenawan, the last is apparently preferable as being most directly derived from the geographical term Keweenaw.

Bayfield, in 1829, recognized the detrital character and source of the débris of the Keweenawan conglomerates, and concluded that they must be later than the traps.

The existence of a succession of interbedded clastics and volcanics 12,000 feet thick about Lake Superior was recognized by Logan as early as 1847, while in 1852 the same author accurately characterized the series as an alternation of sandstones and conglomerates, amygdaloids, and traps. The work of Foster and Whitney on the south shore established about the same time the existence of a similar great succession on Keweenaw Point, although the conglomerates were by these authors regarded as friction conglomerates caused mainly by volcanic action upon the earlier sandstones. Jackson recognized that the conglomerates are of true detrital origin. The first clear appreciation of the contemporaneous interstratified relations between the volcanics and the detrital rocks on the south shore was reached by Pumpelly and Marvine. Their work on this series of rocks was much fuller than any that had gone before, and as a consequence of this the rocks were recognized as a distinct division, to which the term "Keweenaw group" was applied. Logan, on the north shore, included in his "Upper Copper-bearing" rocks what is here called Keweenawan and the unconformably underlying Animikie. He recognized, however, that the two have a very different lithological character. The felsites, quartz porphyries, and other acidic rocks—in the earlier reports frequently called jaspers—and the amygdaloids were by many of the earlier authors supposed to be metamorphosed sandstones. This position is, we believe, for the acidic rocks, held by no writer at the present time, with perhaps one exception, and for the amygdaloids by none. The work of Wadsworth, Pumpelly, and Irving has demonstrated beyond all doubt that these rocks are original eruptives. The Keweenawan is now generally recognized as a series many thousands of feet thick, consisting of interbedded lava flows and water-deposited detrital material, derived chiefly from the contemporaneous igneous rocks. The volcanics are predominant in the lower part of the series, the interstratifications of the two are most frequent in the middle portion, and the upper part of the series is free from volcanics.

The last point to be considered in this connection is the reality of the existence and the position of the so-called crowning overflow of the northwest shore. This was described by Logan, Bell, Selwyn, and others; some were inclined to place it with the Animikie and others with the Keweenawan. Irving, in his general treatise on the copper-bearing rocks, does not recognize this overflow as a general formation, but places the more important flows to which this term has been applied at the base of the Keweenawan. Later work in northeastern Minnesota shows that at the base of the Keweenawan is a great mass of gabbro, the thickness and magnitude of which are incomparably greater than the so-called crowning overflow of Thunder Bay. This gabbro extends from Duluth northeastward to the National boundary, a distance of 100 miles or more, and is at its maximum outcrop more than 20 miles in width. It lies near the base of the Keweenawan, for it comes in contact now with one member of the Animikie and now with another, and in the Mesabi district with Giants Range granite; at other places it is in contact with the crystalline schists of the lower-middle Huronian, and again with the granite and gneiss of the Laurentian; so it is evident that if this gabbro is a part of the regular succession all these rocks were deeply eroded before its appearance. It was long a matter of doubt whether it is a great surface flow or succession of flows, or, as suggested by Irving, an immense reservoir in the nature of an early laccolith or batholith which furnished material for the subsequent diabase dikes and sheets of the Animikie and for basic surface flows of the Keweenawan. The view now prevailing is that the gabbro is a great intrusive laccolith. The evidence, first stated by Grant, is principally the coarse texture of the mass, its shape, and its profound metamorphic effect upon the adjacent rocks.

Van Hise and Clements found that the diabase of Irving's Beaver Bay group and red rock are not surface flows, but intrusives which cut the lavas of the Keweenawan.

RELATIONS OF KEWEENAWAN AND UNDERLYING SERIES.

Concerning the relations of the Keweenawan and next underlying series opinion is nearly unanimous. As these two series were folded together to form the basin of Lake Superior, the earlier writers regarded them as conformable. That they are really discordant was first recognized by Brooks and Pumpelly, who found that the base of the Keweenawan is now in contact with one formation of the underlying series and now with another, and from this general relation they argued an erosion interval. Brooks also brought forward as evidence of this conclusion the wholly unaltered character of the Keweenawan detritals and the simplicity of its folding as compared with the Huronian. The Wisconsin geologists corroborated Brooks's and Pumpelly's results. When the relations of the series on the north shore were closely examined actual evidence of the erosion interval, consisting of basal conglomerates, was found by Irving at Thunder Bay. The same was seen by McKellar, and upon mapping the two series in northeastern Minnesota Irving and Merriam found that the same discordance which was found on the south shore appeared—that is, the base of the Keweenawan is now in contact with one member of the underlying series and now with another. Van Hise and Clements made similar observations about Thunder Bay. The recent detailed mapping of the district north and east of Thunder Bay by W. N. Smith brings out the clearest evidence of the magnitude of the unconformity yet presented. The coarse conglomeratic base of the Keweenawan here rests in turn on the tilted and eroded edges of the slates or the iron formation of the Animikie group and lower-middle Huronian graywackes. His observations were confirmed by the joint committee of the Canadian and the United States geological surveys in 1904. Selwyn found at Thunder Bay no evidence of this erosion interval; but this testimony is negative and stands alone. The belief that there is a physical break at the base of the Keweenawan is supported by a great mass of evidence from many localities.

GENERAL SUCCESSION ACCORDING TO DIFFERENT WRITERS.

In taking the next step downward we come to the complex about which there has been so great diversity of opinion, and it is difficult even yet to see clearly all the results which legitimately follow from the work done. The crude notion that the sandstones, traps, jaspers, gneisses, granites, and all other rocks of Lake Superior represent one great formation, the crystalline phases being more metamorphosed materials, as maintained by some of the earlier geologists, would now hardly be held by anyone. Also it is doubtful if anyone would deny that the rocks below the Keweenawan series are divisible on a structural basis, if the Animikie group be included. The successions deduced by the geologists who have made the most extended study of the Lake Superior region are as follows:

Logan makes the Keweenawan a downward extension of the Lake Superior sandstone. Below the Keweenawan series, as before defined, is a set of slates (the Animikie) of very considerable thickness, which are, however, a part of the "Upper Copper-bearing group," and therefore superior to the original Huronian or "Lower Copper-bearing group." The Animikie rests unconformably upon the Huronian. As to the relations of the Huronian and "Laurentian" about Lake Superior little is said, except that at one place they appear to be conformable and grade into each other. We thus have Logan's succession: Lake Superior sandstone; Keweenawan; Animikie; unconformity; Huronian; Laurentian. The Animikie, as well as the Keweenawan, is regarded as a part of the Cambrian system.

Selwyn's succession differs from Logan's only in that he maintains that all of the rocks underlying the Animikie in Canada constitute one general conformable succession, but divisible into two systems on lithological grounds. These are the Laurentian and the Huronian. This order is also that of Bell. With these authors the "Laurentian" is granitoid and gneissic, while the Huronian is quartzose, hornblendic, schistose, and slaty.

Foster and Whitney's succession is: Keweenawan, which includes the Lake Superior sandstone; unconformity; Azoic—the latter said to be indivisible except on the north shore, and the granites are intrusive rocks later than the "Azoic" slates. On the north shore the Animikie reposes upon the granite. Until recently Wadsworth has held to the same succession as Foster and Whitney. In his last paper, however, he states that it is probable that in the Marquette "Azoic" there are three distinct geological formations or ages, to which he applies, beginning at the base, the terms Cascade, Republic, and Holyoke. The last two are unconformable with each other.

Macfarlane recognizes a "Huronian" and a "Laurentian," but regards both series as wholly of igneous origin and the distinction between the two a lithological one, the basic green schists referred to the Huronian being newer than the granite and gneiss, and the pseudo-conglomerates found in the "Huronian" a consequence of the intrusion of the latter, in which process fragments of granite and gneiss were caught. The Keweenawan is full of débris from the Huronian.

Brooks, Pumpelly, Irving, Chamberlin, Sweet, and Wright recognize about the same general succession: Lake Superior sandstone; unconformity; Keweenawan; unconformity; then a great system of rocks included in the Huronian; another unconformity; and then a complex of granites, gneisses, and schists. Irving in his later work separates from the Huronian and puts in the Laurentian the formation of dioritic schists, obscure green conglomerates, chloritic schists, etc., cut by granite veins in the Marquette district, which Brooks placed as the lowest part of the Huronian, but the relations of which are said not to have been fully made out. There is the further resultant difference between Brooks and Irving that Brooks regards very considerable masses of granite in the Menominee district as the highest member of the Huronian. As this granite is said to overlie conformably the Huronian schists and to send dikes into them, it is suggested that toward the end of the Huronian period there was a great eruptive outflow of granite. As has been seen, these facts are explained by Irving by excluding from the Huronian the granite and the schists cut, although it is recognized that lesser granitic intrusions have occurred since Huronian time.

Rominger, in his earlier work on the south shore, seeing that his dioritic group of Huronian rocks is cut by granite, and considering the former as a sedimentary rock, and finding also, as he believed, actual transitions between the fragmental quartzites and the granites, placed the whole complex as Huronian and regarded the granite as the youngest member. These positions are, however, very largely abandoned in his later unpublished work. That the granite and gneiss existed prior to the deposition of the lowest members of the Huronian and yielded débris to them, is recognized, although contacts are said to be not numerous enough to make possible a discrimination between the original "Primary" granites and gneisses and those of later eruptive origin. The recomposed character of the detrital rocks which repose upon and have derived débris from the granites and gneisses, instead of grading into them, is now seen. It is, however, still maintained that the great mass of the granite and gneiss is an eruptive of later age than the detrital rocks. The dioritic group, which is so frequently cut by granite veins, before considered as the bottom of the Huronian, is recognized as an igneous rock which must be excluded from the sedimentary series. Rominger's succession is, then: Lake Superior sandstone; unconformity; Keweenawan; unconformity; Huronian sedimentary series, which has, however, been disturbed by great intrusions of granite and gneiss, with also basic rocks; unconformity; granite-gneiss-schist complex.

It is therefore to be noted that Brooks, Irving, and Rominger, who have done the most work in the detailed mapping of the rocks of the south shore, reach identical conclusions as to the succession, the only difference being one of emphasis. Rominger insists on the great importance of the later granite gneisses, but does not emphasize the presence of the basal granite-gneiss-schist complex; Irving, on the other hand, reverses the emphasis, while Brooks occupies an intermediate position. It is most significant that these three men, starting with different views, finally reached like conclusions. For a long time Rominger denied the existence of the basement granite-gneiss-schist complex. Irving was slow to recognize the presence of later intrusive granite. In Brooks's earlier work in the Marquette district he did not find the evidence of intrusive granite gneiss which he found later in the Menominee district.

The subsequent detailed study and mapping of the iron-bearing districts of Michigan, Minnesota, and Wisconsin for the United States Geological Survey by Van Hise, Bayley, Clements, Smyth, Leith, Merriam, and others, and for the Michigan Geological Survey by Seaman, Lane, and others, have brought out abundant evidence of the essential correctness of the succession of Brooks, Pumpelly, Irving, Chamberlin, Rominger, Sweet, and Wright, and has of course resulted in further subdivision of the series. The general succession of this group is: Cambrian; unconformity; Keweenawan; unconformity; Huronian, consisting of two and in Michigan three unconformable groups; unconformity; Keewatin green schists, and Laurentian granites and gneisses intrusive into the Keewatin. A principal contribution of these groups has been the recognition of unconformities within the Huronian and the subdivision of the Huronian series into formations and the determination of their order of superposition. Wadsworth's succession for the Marquette district, though differing in names, is also essentially the same as that of the United States Geological Survey for this district, but he places the "Eastern" sandstone below rather than above the Keweenawan series where the two come together on Keweenaw Point. In north-central Wisconsin Weidman finds unconformable series which he correlates with the Huronian, Laurentian, and Keewatin series of the remainder of the Lake Superior region.

Up to 1902 the United States geologists placed much emphasis on the dual nature of the Huronian series. The succession and correlation for the region as a whole was based on this conception. Seaman was the first to establish the facts that the Huronian groups of the Marquette district, where they are best represented, are three instead of two in number; that the lower Huronian of the United States Geological Survey really consists of two unconformable groups, and that the unconformity between these groups is perhaps as great as between those that had previously been called the upper and lower Huronian. This discovery introduced a disturbing factor which required some revision of the general correlation. In no district outside of the Marquette district have all three groups been found, but it has been necesary to determine with which of three, instead of two, groups a given group in any district is to be correlated. The new possibilities in correlation of the Marquette rocks with the Crystal Falls, Menominee, and Minnesota rocks are discussed on pages 359, 362.

Lawson, N. H. Winchell, W. H. C. Smith, McInnes, Coleman, Willmott, and others, working principally on the north shore of Lake Superior, have reached conclusions somewhat different from those of the United States Geological Survey above outlined.

Lawson recognized a physical break at the base of the Keweenawan and a great break at the base of the Animikie. The latter he calls the "Eparchean interval," and believes it to be the greatest of the unconformities in the Lake Superior region. It is, indeed, in the region north and northwest of Lake Superior familiar to him, the most conspicuous of the unconformities, and where the Animikie rests upon deeply eroded Archean rocks it is the greatest of the unconformities; at such localities this unconformity represents two or more unconformities and their intervening groups, just as under the Cretaceous, where the series rests upon the Archean, there is a still greater but not more conspicuous unconformity. He divided the underlying complex about the Lake of the Woods and Rainy Lake, Ontario, into Keewatin, "Coutchiching," and Laurentian, this being the order of occurrence downward, but in age the granitic and gneissic rocks are later than and intrusive in the schistose rocks. In this matter Lawson agrees with the earlier work of Bigsby upon Rainy Lake and that of Dawson upon the Lake of the Woods, except that Dawson did not regard all of the granite gneiss of the Lake of the Woods as later igneous material. These relations are the same as those described by Foster and Whitney and by Wadsworth between the granite gneisses and the "Azoic" slates on the south shore. With Dawson, Lawson agrees that the Laurentian gneiss and granite and the overlying schists are conformable. By both of these writers the schistose rocks of the Lake of the Woods are regarded as sedimentary and largely of volcanic origin. There is the further agreement between Lawson and Dawson for the north shore and Foster and Whitney, Wadsworth, Irving, and Williams for the south shore that they regard the greenstone slates as largely in the nature of volcanic ash. Lawson gives the schistose rocks about Rainy Lake a twofold division, both series being regarded as sedimentary and in apparent conformity, but there are great differences in the materials of which the series are composed as well as in degree of crystallization, and basal conglomerates are found at the bottom of the upper series. Between the two he believes there is a considerable geological break. The upper he regards as the equivalent of the schistose series of the Lake of the Woods. To cover the two series he proposed the system name "Ontarian." Lawson's succession is, therefore: Keweenawan; unconformity; Animikie; unconformity; Keewatin; unconformity; Coutchiching; irruptive unconformity; Laurentian, cutting both Keewatin and Coutchiching.

It is of interest to note that Rominger's early conclusions as to the general relations of the rock series on the south shore were almost identical with those reached by Lawson as to the relations of the different series on the north shore; that is, the dioritic group, the lowest Huronian, is regarded as remelted metamorphosed Huronian sediments, the more crystalline character of the rocks being due to their closer proximity to the volcanic forces; and while the great masses of granite gneiss are below the dioritic group, these rocks are also interspersed with and cut the dioritic rocks, the whole granitic group being regarded as of igneous origin and later in age than the sedimentaries. The likeness of the dioritic group and Lawson's Keewatin at once suggests itself. As has been seen, Rominger's later studies led him materially to modify his opinions and to bring them more nearly in harmony with the conclusions of Brooks and Irving.

Van Hise's examination of the Rainy Lake and Lake of the Woods region led him to the conclusion that Lawson's "Coutchiching," instead of being beneath the Keewatin, really belongs unconformably above it and constitutes the basal portion of the Huronian series, a conclusion subsequently corroborated by the joint committee of United States and Canadian geologists.

Coleman adopted Lawson's classification for the Rainy Lake and Lake of the Woods areas.

W. H. C. Smith followed Lawson's classification in the mapping of Hunters Island and adjacent areas, putting at the base the "Ontarian," divided into "Coutchiching" below and Keewatin above. These are intruded by Laurentian granites and gneisses.

McInnes also followed Lawson in his mapping northwest of Port Arthur, finding the Laurentian to intrude the "Coutchiching" and Keewatin rocks.

A part of the Hunters Island area, mapped by Van Hise, Clements, Bayley, Leith, and Grant in connection with the mapping of the Vermilion district of Minnesota, showed the same general succession as held by the United States Geological Survey for the region as a whole—that is, Animikie or upper Huronian; unconformity; lower Huronian; unconformity; Keewatin green schists; Laurentian granites intrusive into the Keewatin; also granites intrusive into the lower Huronian.

The same was found by W. N. Smith in the Loon Lake region east of Port Arthur.

Van Hise found, beneath the Animikie, rocks that he regarded as typical of the basement complex about Thunder Bay and at other points on the north and east shores of Lake Superior.

Clements found representatives of both the basement complex and the lower Huronian beneath the Keweenawan rocks of Lake Nipigon.

For the Michipicoten district, on the northeast shore of Lake Superior, Coleman and Willmott's succession is: Upper Huronian sediments (including Dore conglomerate); unconformity; lower Huronian greenstones; green schists and iron formation; Laurentian granites and gneisses intruding upper and lower Huronian. This is really the succession, except as to names, of the United States Geological Survey for this district, their upper Huronian corresponding with the United States Geological Survey's lower Huronian, and their lower Huronian corresponding with the green schist portion of the basement complex now called Keewatin. They differ from the United States Geological Survey in not recognizing the presence on the north shore of granites and gneisses older than the sedimentary Huronian, holding all the granites and gneisses to be intrusives.

Alexander Winchell's succession, based principally on Minnesota studies, is: Keweenawan, Huronian, Keewatin, Vermilion, Laurentian. At the base of the Huronian is a great structural break. The three lower series are in conformity and grade into one another. This is much the same as this part of the succession given by N. H. Winchell, except that one great formation, the Ogishki conglomerate, is placed by the latter as a part of the Animikie (Huronian), while by Alexander Winchell it is placed with the Keewatin.

N. H. Winchell's succession is: Keweenawan; Animikie; Norian; Pewabic quartzite (all of which are included in the "Taconic"); Keewatin; Vermilion; Laurentian (which are included in the Archean or "Azoic"). The Keweenawan is doubtfully called Potsdam, and is, with the Animikie, placed as the "Georgia formation;" and the Pewabic quartzite is provisionally placed with the "Potsdam granular quartz." Included in the "Taconic" are the quartzites of Minnesota, Iowa, Dakota, and Wisconsin. The part of the succession placed in the "Taconic" differs from Irving's succession for this part of the column in that the formations which Winchell includes in the "Norian" and Pewabic are regarded as the great basal gabbro mass of the Keweenawan, between the upper Keweenawan and the Animikie instead of below the Animikie. It is not necessary to say that Irving regarded all of these members as pre-Cambrian. The succession within the Archean is the same as that of Lawson, the difference being only that "Vermilion" is substituted for "Coutchiching." Later he used the term "Coutchiching." Also the Keewatin clastics, "Vermilion" schists, and Laurentian gneiss are regarded as in complete conformity, all detrital, and the lower members but more metamorphosed than the upper.

In a later classification N. H. Winchell included in the "Taconic" the Keweenawan and Animikie; in the Archean, "Upper" and "Lower" Keewatin, separated by unconformities. The Pewabic quartzite also was placed with the Keewatin, but was not assigned to either of the main divisions. His Lower Keewatin includes rocks which the United States Geological Survey has referred to the basement complex and lower Huronian. The same is true of his Upper

Keewatin, though for the most part it corresponds with the United States Geological Survey's lower Huronian. His Animikie and Keweenawan correspond with those of the United States Geological Survey. He concludes that the Sioux quartzite, Baraboo quartzite, and New Ulm quartzite are unconformably above the Animikie and below the Keweenawan. For this no evidence is presented. He concludes further that the granites and gneisses show gradation through schists into true fragmental rocks, and thus have been derived from the metamorphism of the sedimentary rocks. In the same manner gabbro has been derived from the metamorphism of greenstones with their clastic variations. The iron formation of the Animikie of Minnesota, classed as sedimentary by all other writers, is held by Winchell to be of volcanic origin.

Bailey Willis was the first to approximate the succession in the western Vermilion district, though his evidence was incomplete and his succession faulty. His succession is, from the base up: (1) Chloritic schist; (2) jasper interstratified with layers of hard blue specular ore, which also occurs in ore bodies of considerable extent running across the bedding, thickness 200 to 600 feet or more; (3) chloritic schist, similar to 1, original thickness probably about 150 feet; (4) quartzite, containing grains of magnetite which make it a readily recognized magnetic formation, probable thickness 200 feet; (5) conglomerate, consisting of sandstone pebbles and traces of black slate inclosed in siliceous chloritic schist; (6) compact homogeneous rock, which may be an eruptive quartz diorite, but is considered a metamorphosed sedimentary transition bed between 5 and 7; (7) black clay slate.

Smyth's and Findlay's succession for the western part of the Vermilion range is: Fragmental slate formation, overlain by the iron-bearing formation. Both are intruded by basic and acidic igneous rocks, which exceed in quantity the sedimentary later rocks. This succession is directly the reverse of that of Willis and later of Van Hise, Clements, Bayley, Merriam, Leith, and others for the United States Geological Survey. Their succession is: (1) Keewatin greenstone and green schist, largely basaltic, with ellipsoidal and other surface structures, interbedded and overlain by iron formation with a small amount of slate; (2) Laurentian granites, gneisses, and porphyries; (3) lower Huronian conglomerates (Ogishke and Stuntz formations), grading up into graywackes and slates (Knife Lake slate); (4) upper Huronian quartzite, iron formation, and slate, restricted to the east end of the district. The great conglomerates at the base of the fragmental series, containing fragments of iron formation and green schists of the basement complex, are held by Smyth and Findlay—on evidence which we believe to be quite insufficient—to be breccias. In their earlier work Irving and Van Hise placed the iron-bearing formation of the Vermilion district in the lower Huronian, and the overlying conglomerates, Ogishke and Stuntz, in the upper Huronian. Later work resulted in the assignment of the iron formation, with its closely associated green schists, to the green schist portion of the basement complex, and the overlying sediments were assigned to the lower Huronian.

The succession of Grant, N. H. Winchell, H. V. Winchell, and Spurr of the Minnesota Survey for the Mesabi district was: Keweenawan; unconformity; Animikie; unconformity; Upper Keewatin; possible unconformity; Lower Keewatin. Grant recognized in the "Upper Keewatin" similarities to the lower Huronian of other parts of the Lake Superior region, although it was not discriminated in the mapping. Leith's succession differs from that of the Minnesota Survey in the discrimination of a well-defined sedimentary series beneath the Animikie, corresponding roughly to Grant's Upper Keewatin, and separated by a marked unconformity with the basement complex. His succession is: Keweenawan; unconformity; Animikie or Upper Huronian; unconformity; Lower Huronian; unconformity; Archean (includes the Keewatin and Laurentian). Hall, in central Minnesota, finds granites, gneisses, and gabbros of the basement complex overlain by Huronian quartzites and slates, and later Leith and Zapffe mapped here a great series of upper Huronian slates and iron formation, occupying much of central Minnesota, and correlated the rocks with the upper Huronian of the Mesabi district.

A general result of the later work in Minnesota, and particularly that of the United States geologists, Van Hise, Clements, Bayley, and Leith, has been the recognition of the existence of large areas of Huronian and Keweenawan granite which had before been assigned to the Archean. They have long maintained that the granites of the region comprise both Archean and Huronian granites, and that it remains for detailed mapping to indicate the relative importance of the two. The Canadian geologists have held that the granites, nearly all of which they have mapped as Laurentian, are almost entirely intrusive into the Huronian series. In this they are followed in large part by the Minnesota geologists.

Finally the joint committee of the Canadian, Ontario, United States, and Michigan geological surveys, composed of Frank D. Adams, Robert Bell, A. C. Lane, C. K. Leith, W. G. Miller, and Charles R. Van Hise, after visiting the Marquette, Gogebic, Vermilion, Mesabi, Rainy Lake, Lake of the Woods, Port Arthur, and Lake Huron districts in 1904, recognized a succession for the entire region identical with that used by the United States Geological Survey in its mapping in Michigan and Minnesota. Lawson's Coutchiching was found to be essentially above rather than below the Keewatin and to belong with the Huronian series. His Keewatin was thought to be typical of the green schist portion of the Basement Complex for the region as a whole, and it was recommended that his name, Keewatin, be used, on the ground of priority, for this division of the Basement Complex, in place of the term Mareniscan, proposed by Van Hise. The succession and nomenclature recognized and adopted have already been given. (See p. 326.)

From the foregoing statements it might be concluded that Lake Superior stratigraphy below the Keweenawan is in a state of greater confusion that it really is, for a closer examination of the various successions shows that many apparent discrepancies are not real, if conclusions are not extended beyond the field studied in each case. While there is still some difference of opinion as to names and major correlation, practically all who have any detailed knowledge of the Lake Superior and Lake Huron regions have recognized the general succession of the groups and formations mentioned in the joint committee report. Confusion has resulted because the conclusions built up from a study of a small part of the region have been assumed to apply to the whole, because the groups locally have been wrongly placed in the general succession, and because different names are used for the same thing. The Lake Superior region is so large that no one has had or can have a detailed personal knowledge of more than a small part of it.

DEFINITIONS OF "AZOIC," LAURENTIAN, KEEWATIN, ARCHEAN, HURONIAN, ETC.

Before proceeding further it will be well to summarize the lithological characters of the pre-Keweenawan rocks included by the various writers under the terms applied to the different series in different districts, although this will result in repeating to some extent the preceding paragraphs. It is here much less easy to make definite statements than in the case of the Lake Superior sandstone and the Keweenawan.

"*Azoic.*"—As used by Foster and Whitney and those who followed these authors, "Azoic" was made to include everything below the Keweenawan except the rocks which are plainly igneous. It covered conglomerates, quartzites, slates, and marble, as well as the gneisses, mica schists, hornblende schists, etc.; that is, rocks which vary in character from plainly clastic, as conglomerates, to completely crystalline. The granites, syenites, greenstones, greenstone slates, iron ore, jasper, etc., were regarded as igneous rocks, in part contemporaneous with and in part newer than the rocks of the "Azoic" system, all of which were supposed to be of detrital origin, but in age earlier than the Keweenawan.

Laurentian.—As used by most of the earlier Canadian geologists, "Laurentian" covers most of the light-colored granites and coarse-grained gneisses, both older and younger than the associated rocks, but in general regarded as the basement upon which associated rocks were formed. It was recognized that these rocks are cut by basic eruptives. This usage was followed by many of the American geologists up to the time of Brooks, who excluded from the " Laurentian " the large part of the granite and gneiss which the Canadians believed to be of later age and intrusive. Dawson made the same discrimination in the region about the Lake of the Woods. Irving, in his later work, differed from those who preceded him in that he included in the "Laurentian " all the thoroughly crystalline schists, with some of the obscure green schist conglomerates; that is, he placed as a part of the " Laurentian " a large group of finely schistose rocks cut by granite veins which had heretofore been regarded as greatly metamorphosed detrital material and had been placed in the Huronian. He also regarded as belonging here many of the fine-grained crystalline schists of similar character on the north shore, placed by the earlier Canadian geologists with the Huronian. For this " Laurentian," increased in magnitude, he used the term Archean. Lawson, McInnes, W. H. C. Smith, Coleman, Willmott, and Alexander and N. H. Winchell use the term " Laurentian " to cover practically the same class of rocks as the earlier Canadian geologists, although Lawson differs from them in regard to their origin and age. Coleman and Willmot emphasize strongly the intrusive contact of the " Laurentian " with the sedimentary Huronian and maintain that it includes no rocks older than the Huronian sediments.

It was early remarked by Macfarlane, and later by Whittlesey, Brooks, and Rominger, that the Laurentian of Lake Superior differs from that system in eastern Canada in containing no limestones, quartzites, iron ores, or other rocks of the plainly detrital class. Brooks and Chamberlin remark that it is doubtful whether the Lake Superior Laurentian is the equivalent of the eastern " Laurentian " of Canada. Van Hise and others of the United States Geological Survey have used the term Laurentian for granites and gneisses of the basement complex or Archean age. This definition was recommended also by the joint committee of Canadian and United States geologists, but as a concession to the difficulties of mapping in Canadian territory it was agreed that the term should also be used, preferably with an explanatory note, for large areas of granite and gneiss in which the parts of Archean or basement complex age have not been separated from those of later age. Still later, Lane and Seaman have used " Laurentian " as equivalent to Archean.

Keewatin.—This name, first applied by Lawson to the greenstones, green schists, and iron formation of the Lake of the Woods area, has been by other writers applied to green rocks of different ages. In northern Minnesota the term " Keewatin," as used by N. H. Winchell, includes rocks of the basement complex and of the Huronian. Van Hise, believing that the term Keewatin was not originally applied to a structural unit, and believing also that its usefulness had been impaired by its promiscuous application to green rocks of different ages elsewhere, proposed the term "Mareniscan" to cover the greenstone, green schist, and iron formation portion of the basement complex. When Lawson's original Keewatin area of the Lake of the Woods was examined by the joint committee of Canadian and United States geologists it was ascertained that the Keewatin of this area is a structural unit, and the term Keewatin was recommended to cover all of the greenstone, green schist, and iron formation portion of the basement complex in place of "Mareniscan." This is the sense in which Keewatin is now generally used.

"*Coutchiching.*"—This name was used by Lawson for a series of mica schists in the Rainy Lake district which he believed to underlie the Keewatin. These rocks were subsequently found by Van Hise to be metamorphosed Huronian sediments above the Keewatin. Winchell, in the belief that he was following Lawson, applied the term "Coutchiching" to hornblende schists resulting from the metamorphism of Keewatin greenstones by the intrusion of granites in northeastern Minnesota. At the present time the term is practically abandoned, except perhaps by Lawson.

Archean.—With the Canadian geologists Archean has always meant pre-Cambrian, and in this they have followed Dana. As some of them have included Keweenawan and Animikie rocks in the Cambrian, their "Archean" means pre-Animikie. Archean with Van Hise and others of the United States Geological Survey covers the basement complex beneath the Huronian.

By the United States geologists the Archean was formerly regarded as essentially of igneous origin and as comprising both acidic and basic rocks. It was not until 1899 that the geologists of the United States Geological Survey recognized the presence in the Archean of chemically deposited iron formation and fragmental slates. The iron formation and associated slates had been regarded as ferruginous vein material or had been assigned to the Huronian. Reexamination of the relations of the iron formation and slate of the Michipicoten district and of Pine street, Marquette, to the associated greenstones and green schists, led Van Hise, in 1899, to suspect that they belong to the same series, as had been previously thought by Seaman from studies in the Marquette district. In the same year Leith, by the discovery of lower-middle Huronian rocks in the Mesabi district identical in structure and lithology with those of the Vermilion district, was able to show that the slates, graywackes, and conglomerates of the Knife Lake slate of the Vermilion district are unconformably below the upper Huronian. It followed that the iron formation, slate, and associated greenstone of the Vermilion district, in turn unconformably below this series, are Archean. Prior to that time the greenstones, with intrusive granites, had been referred to the Archean by the United States geologists, the iron formation to the lower Huronian, and the Knife Lake slate had been correlated with the Animikie as upper Huronian. The Minnesota Survey had held the Knife Lake formation to be unconformably below the Animikie, but had made no satisfactory discrimination of the lower-middle Huronian sediments from the Archean greenstones and iron formation. Since this conclusion concerning the Archean age of the iron formation associated with greenstones and green schists was reached, increasing quantities of iron formation, slate, and occasionally carbonate considered to be of this age, have been discovered, particularly in Ontario. In fact, outside of the Animikie district, on the northwest shore of Lake Superior, practically all the iron formation of Ontario in the vicinity of Lake Superior is believed to belong to the Archean. The iron formation is in layers and lenses which have such relations to the greenstones and green schists, consisting largely of fragmental volcanic material, as to suggest that the igneous and sedimentary rocks have been interbedded and then infolded in an intricate fashion. It is impossible to separate them on any structural basis. An area of greenstone a mile square may contain a hundred small lenses of iron formation. In recognition of the close relation, both structural and chronological, of the iron formation, slate, and carbonate, with the rocks of the Archean the term Archean is retained for the entire group. While this term had previously been used for rocks believed to be essentially of igneous origin, forming the basement complex of the region, it had been recognized that rocks of possible sedimentary origin were doubtless included in this basement complex, as for instance the Palmer gneiss and the conglomerate at Deer Lake in the Marquette district and the Quinnisec schists of the Menominee district. So general had become the use of the term Archean, however, to cover strictly igneous rocks basal to the Algonkian elsewhere in the United States that the formal reference to the Archean in the Lake Superior region of small bodies of recognized sediments has led to confusion and much opposition. The definition and use of the term Archean are discussed on pages 26, 361.

Huronian.—The Lake Superior "Huronian" of the larger number of the Canadian geologists includes the quartzites, slates, fine-grained green schists, all of which are sometimes conglomeratic, and the pebbles, which are often distorted and metamorphosed. It also includes the mica schists, hornblende schists, and fine-grained gneisses bearing calcite, with certain ferruginous schists and basic and acidic volcanic products. The attitude of the "Huronian" schists is either vertical or steeply inclined. The Animikie is not included in the "Huronian." On the south shore Brooks and Pumpelly in their earlier work included in the Huronian all the rocks in character like those placed in this system on the north shore, with also large areas of rocks the clastic character of which is evident, such as limestones, ferruginous beds, slates, graywackes, etc., which while always tilted or gently folded have not the schistose structure of the "Huronian" of the north shore, but rather resemble the Animikie. Later, Brooks placed as the upper member of the "Huronian" large areas of gneiss and granite which had earlier been regarded as Laurentian. Rominger went a step farther and recognized in his published report on the south shore the "Huronian" only, seeing as he did that a part of the granite gneiss certainly cuts a portion of the schistose rocks which had been regarded as "Huronian." He thus included in the "Huronian" the granite gneisses which are equivalent to Lawson's "Laurentian," and reverted to the position of Foster and Whitney, making his "Huronian" the equivalent of their "Azoic," one indivisible system. In Rominger's later unpublished manuscript, however, he distinctly recognizes besides a later intrusive granite an earlier granite gneiss upon which the lowest detrital beds were deposited, although he nowhere states whether this is considered Laurentian or not. Irving excludes from the Huronian on the south shore large areas of green crystalline hornblende schists, chlorite schists, and green schist conglomerates cut by granite veins, heretofore called "Huronian;" that is, he included in the Huronian only those detrital rocks the clastic character of which is apparent or which can be traced into the clastic rocks, such as the quartzites, limestones, ferruginous beds, argillaceous slates, metamorphic mica schists, etc. In his Huronian he included the Animikie on the north shore, placed above the Huronian by the Canadian geologists.

Animikie.—The Animikie includes the unaltered, or little altered, gently inclined or folded slates, graywackes, and ferruginous beds on the north shore and in northeastern Minnesota.

Basic and acidic eruptives.—All writers recognize as belonging to the series designated by the foregoing terms interbedded and cutting basic and acidic eruptives of various sorts, although in the Animikie acidic eruptives are insignificant in amount. Many of the fine-grained green schists, with some exceptions regarded in early days as much metamorphosed sedimentary "Huronian" rocks, are now considered by all to be much altered eruptives, either of surface or of deep-seated origin, their present structure being due to secondary causes. That acidic eruptive material should be found plentifully cutting the clastic series is not at all surprising. Acidic eruptions were abundant and widespread in the Lake Superior region as late as Keweenawan time, as is attested by the original acidic rocks of the copper-bearing series, and still more emphatically by the vast amount of débris from felsites, quartz porphyries, etc., found in the interlaminated detrital beds. That so few acidic dikes are found in the upper Huronian of the south shore can be explained only by the fact that the acidic eruptives of the Keweenawan are mostly remote from the Marquette, Menominee, and Penokee districts. A closer study will probably show in these districts a greater abundance of acidic eruptives than has been supposed. The deep-seated pipes and bosses formed by the eruptions of the Keweenawan felsites and porphyries perhaps crystallized in the form of granite. It may well be that large masses of intrusive granite are of Keweenawan or Animikie age.

Keweenawan ("Keweenian,". "Nipigon," "Copper-bearing").—Keweenawan has been used from the beginning for the series of interbedded eruptives and sediments with basic intrusives unconformably overlying the Animikie and underlying the Potsdam. Logan included the copper-bearing series and the Animikie rocks in his "Upper Copper-bearing group," and thought it to be the downward extension of the Cambrian.

The Keweenawan is thought to be of middle or lower Cambrian age by most of the Canadian geologists and by Winchell, Seaman, and Lane. The geologists of the United States Geological Survey believe it to be pre-Cambrian.

BASIC ERUPTIVES AND STRATIGRAPHY.

At one other point the problem of Lake Superior stratigraphy has been made more difficult by certain of the geologists than was necessary. The diabases, diorites, and gabbros were by several writers in early days, and recently by N. H. Winchell, regarded as metamorphic sedimentary rocks. Logan, Murray, and Foster and Whitney are notable exceptions. Partly as a consequence of this fact came the minute subdivision of the rocks of the Marquette, Menominee, Penokee, and other districts. As all now regard these rocks as intrusives, the facts that they are often in bosslike masses and that when interleaved they do not necessarily continue for any great distance present no difficulty, while a great formation like the "Upper Slate" of the Penokee and Marquette districts is left as a whole rather than divided into a number of members separated by layers of greenstone. Also it is now known that the "dioritic schists" are ancient eruptives, in part contemporaneous and interbedded with the sedimentary rocks. The volcanic character of these rocks was suggested by Foster and Whitney, and their igneous origin was appreciated by Rominger. Later investigations by Wadsworth and Williams, with the microscope, led to the same conclusion. These groups of surface volcanics and associated fragmental rocks have now been found in the Archean, the lower Huronian, the middle Huronian, and the upper Huronian, and those of the four horizons present astonishing lithological similarities. This makes the correlation of volcanics extremely difficult. There are several areas of volcanics concerning whose age little more than a guess can be made. A close study may demonstrate that some of the fresher eruptives in both the upper and the lower and middle Huronian, including the great intrusive beds of the Animikie, are really Keweenawan in age. Also the numerous very fresh dikes of like character cutting the Archean doubtless represent the same manifestation of igneous activity. Strong and Rominger long ago suggested that the fresh dikes in the St. Louis River district were the filling of the pipes through which passed the outflows of Keweenawan time. This idea is not only plausible for this district, but is probably true for the entire Lake Superior region.

UNCONFORMITY BENEATH THE ANIMIKIE, OR UPPER HURONIAN.

A great unconformity at the base of the Animikie group was recognized by the early Canadian geologists. They first placed the Animikie with the Huronian, but the fact that unconformably below it was another group which also resembled the Huronian led the later Canadian geologists to exclude the entire Animikie from the Huronian, and they have thus restricted the term in this district to the pre-Animikie Huronian rocks. Lawson expressed his view of the importance of the unconformity when he proposed to call it the "Eparchean interval."

The unconformity at the base of the Animikie was also recognized by the Winchells near Gunflint Lake and westward along the Mesabi range, although they suggested the possibility of a gradation between the Animikie and the underlying "Keewatin" and "Vermilion" rocks. Van Hise, prior to the detailed work of the United States Geological Survey in Minnesota, believed the Animikie to grade into the steeply inclined and metamorphosed sediments of the Vermilion district—the lower-middle Huronian of the present classification, then called the "Upper Vermilion series." He classed the Vermilion sediments together with the Animikie as upper Huronian, placing in the lower Huronian the iron formation and green schists of the Vermilion iron-bearing district. The detailed mapping by Van Hise, Clements, Bayley, Leith, and Merriam of the Vermilion and Mesabi districts in the later part of the last century brought out conclusive evidence of the unconformity of the Animikie group upon the underlying Vermilion group and its equivalents. The latter rocks were therefore called lower Huronian (now lower-middle) and the unconformity between them and the Animikie became known as an inter-Huronian unconformity. The Michigan and Wisconsin geologists include in the Huronian the equivalents of both the Animikie and the pre-Animikie Huronian, and while their reports contained facts which clearly pointed to a discordance within the rocks referred to the Huronian, no attempt was made to carry these facts to their conclusion and to subdivide the series. Alexander Winchell, in his last paper, which appeared almost simultaneously with his death, announced definitely that two series had been confounded in the Huronian.

Evidence of this break in the Marquette district was first noticed by Foster and by Foster and Whitney, who found over the ore horizon at what has since become the Republic mine, and at one or two other localities, a conglomerate bearing fragments of the ore, jasper, and other rocks associated with the iron ore. It was next noted by Kimball, who mentions beds of specular conglomerate. Credner describes a conglomerate over the iron formation at Michigamme mine, the fragments of jasper and quartz being in an iron and quartz base. Brooks describes the upper quartzite of Republic Mountain and that at the New England mine as a conglomerate containing fragments of ore. Rominger noticed the break at so many places that he remarked that above the iron-bearing rock is generally a very coarse quartzite conglomerate which often has the character of a coarse-grained ferruginous quartzite, the fragments of which are chiefly ore, jasper, and quartz. This occurrence is so general as to suggest to this author that great disturbances not of a local extent must have occurred at the end of the era of iron sediments. Wadsworth says that these conglomerates mark old waterworn beaches existing after the jasper and ore were in situ in nearly their present condition. Believing in the eruptive origin of these rocks, Wadsworth did not regard the conglomerates as evidence of the existence of more than a single series; but that author later changed his opinion in this particular. Irving recognized the break, and the fragments included in the conglomerate overlying the iron belt are said to prove the existence of the jaspery and chalcedonic material in its present condition before the formation of the upper quartzite. Later the break was noticed by the Winchells, and N. H. Winchell regarded it as so great that the rocks above the break were provisionally referred to the Potsdam. On the basis of the two unconformities the Huronian of the Marquette district is now divided into three groups, upper, middle, and lower.

In the Menominee district the observations of Brooks seemed to indicate the presence of an unconformity within the Huronian series. It was first thought by Pumpelly, Irving, Van Hise, and others that the break should come above the iron-bearing formation, but the detailed mapping by Bayley, Clements, and Van Hise suggested one below the iron-bearing horizon and above the quartzite and marble of the lower Huronian. The evidence of considerable unconformity is slight.

In the Gogebic district the unconformity at the base of the Animikie was recognized by the early geologists, and particularly by Brooks. The underlying rocks were referred to a "Laurentian" complex. Irving, in his Wisconsin Geological Survey work, referred to the underlying cherty limestone as a peculiar phase of quartzite at the base of the Animikie. The work of Van Hise leading to the publication of Monograph XIX of the United States Geological Survey proved, by evidence at many points along the range, the existence of an unconformity between the Animikie and this limestone and underlying rocks.

UNCONFORMITY BENEATH THE HURONIAN SERIES.

Bell and Selwyn find no evidence of discordance between their "Laurentian" and "Huronian." Bell, in 1873, says the distinction between the "Laurentian" and "Huronian" is chiefly of a lithological character, while Selwyn, in 1883, states that he can give no better reason for supposing that certain sets of beds belong to the "Laurentian" and others to the "Huronian" than a considerable difference in lithological character, the former being essentially granitoid, gneissic, and feldspathic, while the latter is quartzose, hornblendic, schistose, and slaty.

Dawson (Sir William), Logan, and Bell all mention granite and gneiss fragments in the original Huronian east of Lake Superior, and Logan clearly believed the two to be unconformable. Irving found additional evidence in favor of this unconformity. Work of Pumpelly and Van Hise has shown that the lowest member of the original Huronian, as mapped by Logan, rests with a great unconformity upon the basement complex, the "Laurentian" of Logan. Selwyn, although thinking the "Huronian" and "Laurentian" conformable, states that "Laurentian" pebbles occur in the "Huronian."

In the Lake of the Woods and Rainy Lake districts Lawson failed to recognize the unconformity between the "Huronian" and the underlying basal complex, now recognized in that district by the joint committee; indeed, he believed the "Huronian" (his "Coutchiching") to lie below the basal greenstones (his Keewatin). Pumpelly and Smyth differ from Lawson in that they find a great structural discordance between the basal clastic series east of Rainy Lake and a fundamental complex consisting of granite, gneiss, and schist, while finding the superinduced foliation of both series parallel.

In Minnesota the Winchells, although recognizing the plane between the clastics and crystallines as a boundary between two series of rocks, maintain conformity and gradations, although Alexander Winchell suggests the possibility that the apparent conformity is superinduced by subsequent dynamic action. Van Hise and Irving early recognized the existence of an unconformity beneath what is now known as the Huronian series, but at that time they believed the iron formation underlying this unconformity to be itself Huronian, and therefore the unconformity to be an inter-Huronian unconformity. The break between the Huronian sediments and the basement complex in Minnesota was not recognized as such prior to the detailed work of the United States Geological Survey in the later part of the last century.

In the Mesabi district lower-middle Huronian sediments were not discriminated from the green schists of the basement complex by the Minnesota Survey—both were included under "Keewatin." Grant suggested their possible separation, and Leith discriminated a lower Huronian sedimentary series of considerable magnitude and found decisive evidence of its unconformity on the green schists of the basement complex.

The Marquette district on the south shore, next to be taken up in geographic order, should perhaps have been discussed first because it was the first district in which the unconformity between the Algonkian and the Archean was clearly recognized.

Unconformable contacts have been found at many localities, but here the clastic series are folded, and certain of the contacts between the clastics and the crystalline complex, by overlapping, are below upper members of the clastic series rather than truly basal contacts. Of the two localities cited by Brooks for the unconformity between the Huronian and the Laurentian, that at Republic Mountain is clearly between the lower part of the Huronian series and the granite-gneiss-schist complex, while that at Plumbago Creek, in the L'Anse district, is certainly below a high horizon. Of the many localities cited by Rominger and Irving in which there are contacts between the granite-gneiss-schist complex and the overlying clastics, if Brooks's succession be accepted, several belong well down in, if not actually at the base of, the Huronian series. At these contacts the clastics are generally conglomerates, built up chiefly of the débris of the underlying rocks, and oftentimes so thoroughly cemented as closely to resemble them and to lead to the conclusion, if not carefully examined, that there is a real transition between the clastic and crystalline rocks. As already indicated, this was at first Rominger's opinion, and the apparent transition was taken to indicate a gradual metamorphism from the conglomerates to the granite or schists, as the case might be. But Rominger's later studies led him to see, as did also Irving, that these basal conglomerates are recomposed rocks resting upon an earlier formed crystalline and often granitic base. Brooks, Rominger, and Irving all hold that in the Menominee district contacts are found between very low, or the lowest, members of the clastic series and the granite-gneiss complex, the relations being those of profound unconformity.

In the Gogebic district the unconformity between the Huronian and the basement complex was first thought to be at the base of the Animikie, but the cherty limestone was found by Irving and Van Hise to be below this break and to have such distribution as to indicate its unconformity upon the true basement complex. Since that time Seaman and Sutton have discovered a quartzite and conglomerate beneath the cherty limestone of the lower Huronian, in direct and discordant contact on the schists of the basement complex, affording final proof of an unconformity which had been believed to be present from the distribution.

As before stated, Brooks, Rominger, and Irving—the three who had done the most detailed and continuous work on the south shore—had at the outset different opinions as to the relations of the clastics to a basement granite gneiss, but they all came to the same final conclusion, that between the two is a great structural break. Pumpelly and Chamberlin, who have also done much general work in this region, agree with this conclusion. While this is true, all these writers do not agree as to the position at which this plane is found in every district.

The later detailed work of Van Hise, Bayley, Clements, Smyth, Merriam, and others for the United States Geological Survey in each of these districts has developed evidence at many points of the existence of an unconformity at the base of the Huronian series.

Coleman and Willmott have recognized the existence, on the northeast shore of Lake Superior, of a break between the Huronian sediments and the Keewatin green schists, although they classed the former as upper Huronian and the latter as lower Huronian. They do not recognize the break between the Huronian sediments and the Laurentian, holding that the latter are all intrusive.

NOTES.

[1] Third annual report of the Geological Survey of Michigan, by Douglass Houghton. State of Michigan, House of Representatives, No. 8, pp. 1–33.

[2] Fourth annual report of the State geologist, Douglass Houghton. Idem, No. 27, pp. 184. See also Metalliferous veins of the Northern Peninsula of Michigan, by Douglass Houghton. Am. Jour. Sci., 1st ser., vol. 41, 1841, pp. 183–186.

[3] Geology of Porters Island and Copper Harbor, by John Locke. Trans. Am. Phil. Soc., vol. 9, 1844, pp. 311–312, with maps.

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CHAPTER IV.

AREA NORTH AND NORTHEAST OF LAKE HURON, INCLUDING THE ORIGINAL HURONIAN DISTRICT.

SUMMARY OF LITERATURE.

BIGSBY,[1] in 1821, gives the earliest geological account of the north shore of Lake Huron. He found north of the North Channel two series of rocks, one of granite, gneiss, and trap, which was placed by him with the Primitive; the other, without mentioning distinct characters, he called the Transition formation.

MURRAY,[2] in 1845, finds Primary and Metamorphic rocks to comprise the whole country to the north of Lake Simcoe and the northeastern shores of Lake Huron. The rocks are similar in appearance to the masses which compose the Thousand Isles, and include granite, syenite, and gneiss, as well as a coarse micaceous sandstone, which at one place presents evidence of stratification.

LOGAN,[3] in 1847, finds, after passing over 63 miles of lower metamorphic or syenitic gneiss on the Ottawa, after leaving the Mattawa (nearing Lake Temiscamang), a succession consisting of (1) chloritic slates and conglomerates, (2) greenish sandstones, and (3) fossiliferous limestones. The conglomerates often hold pebbles and bowlders, sometimes a foot in diameter, of the subjacent gneiss, from which they are chiefly derived. So indurated is the rock that the fracture breaks across the pebbles. The sandstone is of a sea-green color, and appears to be composed of quartz and feldspar, with occasional flakes of mica. The volume of formation 1 is probably not less and may be very much more than 1,000 feet, while that of the sandstone is between 400 and 500 feet. Formation 3, fossiliferous limestone, is often conglomeratic at its base, containing pebbles, fragments, and bowlders of the sandstone beneath in a calcareous cement. Some of the harder beds abound in chert, and many of them are fossiliferous, the organic remains leading to the opinion that this rock is equivalent to the Niagara of New York. That these limestones are unconformable with the slates appears almost certain, but whether the intermediate sandstones are conformable with one or both of these can not be asserted, nor can it be asserted that the slates are conformable with the gneiss.

LOCKE,[4] in 1847, having visited Echo Lake and the Bruce mine, finds the rocks of the North Channel to consist of sandstone, talcose slate, and limestone, all metamorphosed by trap rock. The slate contains some pebbles of Primitive rock, and thus approaches a conglomerate. The limestone at Echo Lake shows original stratification, and is traversed by seams of hard metamorphic slate, being nearly in the condition of a jasper. They are undulated, contorted, and pleated in a beautiful manner.

CHANNING,[5] in 1847, reports on an examination of Sugar Island, Sailors Encampment Island, St. Joseph Island, and the main shore to Sault Ste. Marie on the American side. Metamorphic sandstone quartz, chlorite-slate quartz, feldspar rock quartz, chlorite, granite, and syenite are all found and are constantly intersected by the trap dikes. At Echo Lake is a metamorphic sandstone quartz containing a stratum of pebbles converted into jasper. On Sugar Island is found metamorphic sandstone containing fragments of metamorphic sandstone and gray gneiss.

MURRAY,[6] in 1849, describes the continuation of his work on the north coast of Lake Huron west of French River and upon the adjacent Manitoulin Islands. The pre-Potsdam group of rocks consists, first, of a metamorphic series, composed of granitic and syenitic rocks in the forms of gneiss, mica slate, and hornblende slate; and, second, in the ascending order, of a stratified series, composed of quartz rock or sandstones, conglomerates, shales, and limestones, with interposed beds of greenstone. The first of these series is in so highly a disturbed condition and is so much contorted that it is impossible to ascertain its thickness. The second series occupies the whole north coast of Lake Huron, with many of its neighboring islands, between Little Lake George and Shebawenahning. There was no opportunity of determining the breadth of country this series occupies and the thickness it attains. The quartzites sometimes pass into a sandstone, and into a beautiful conglomerate, whose pebbles are chiefly of blood-red jasper. Besides the jasper conglomerates there are other conglomerates, the pebbles and bowlders of which are of syenite, varying from those of small size to those 2 feet in diameter; and these are sometimes in a greenish quartz rock as a matrix and sometimes in a greenish slate, more frequently the latter. Numerous greenstone dikes traverse the stratified series, and greenstone masses are interposed among the sedimentary beds. On some small islands granite veins and trap dikes were found breaking through the quartz rock, on one of which the latter beds dipped in opposite directions on opposite sides of the granite, and on another the quartz rock was found reclining on the granite, the contact being seen. The fossiliferous series is supported unconformably upon the older rocks.

LOGAN,[7] in 1849, next gives a general account of the geology of the north shore of Lake Huron. An area of rocks 120 miles long and from 10 to 20 miles wide is placed in a single formation. This formation rests unconformably below the Silurian, as shown by the fact that the latter horizontal strata rest upon the uptilted edges of the quartz rock, fill the valleys between, and overtop the mountains. On account of the eruptive material which the formation contains it is placed as the probable equivalent of the copper-bearing group of Lake Superior. The series is divided into rocks of sedimentary and rocks of eruptive origin. The sedimentaries consist of sandstones, conglomerates, slates, and limestones. The greenstones are of igneous origin, and are of two classes, intrusives and overflows. The intrusives are in part as sheets and in part as dikes. The various kinds of sedimentary beds grade into each other, while the greenstones do not thus grade into the sediments, and therefore present a strong contrast to the real sedimentary beds. The dikes and overflow sheets are lithologically alike, and the dikes reveal a history which has two or three episodes. The chief difference in the copper-bearing rock of Lakes Huron and Superior seems to lie in the great amount of amygdaloidal trap in the latter and of white quartz or sandstone in the former; but there are strong points of resemblance; so it is highly probable, if not almost certain, that they are equivalent and beneath the lowest fossiliferous deposits. On the east and west the series seems to repose on granite.

MURRAY,[8] in 1850, gives the result of a survey of Spanish River. On this stream he finds exposed a granitic or metamorphic group and a quartz-rock group. The latter contains quartzites, slates, and conglomerates, holding sometimes pebbles of jasper, but more often of syenite or granite, as well as limestones and dikes and beds of intrusive greenstones, and can scarcely be less than 10,000 feet thick. The granitic group appears to rise from beneath the metamorphic group at two places.

LOGAN,[9] in 1852, states that on Lake Huron the Lower Silurian group rests unconformably upon a siliceous series that contains one band of limestone, about 150 feet in thickness, having leaves of chert, but without discovered fossils. The series includes the copper-bearing rocks of that district, is interstratified with igneous masses, and has a thickness of at least 10,000 feet; it is supposed to be of the Cambrian epoch. The gneissoid group is probably still older, and its condition is such as to make it reasonable to suppose that it consists of altered aqueous deposits.

MURRAY,[10] in 1857, describes several of the more important streams between Georgian Bay and Lake Nipissing. They embrace two of the oldest recognized geological formations, the Laurentian and the Huronian; the rocks of the latter are more recent and have been observed to pass unconformably below the lowest of the fossiliferous strata of the Silurian system. The contorted gneiss of the Laurentian series, with its associated micaceous and hornblendic schists, spreads over the country to the south and east, while the slates, conglomerates, limestones, quartzites, and greenstones of the Huronian occupy the northern and western parts. The difference in lithological character between the two formations is always sufficiently apparent, but though both were found a short distance apart the immediate point of contact was always obscure, and a mass of greenstone of rather coarse grain was usually the first intimation of the proximity of the higher rocks. Whether this greenstone is a contemporaneous flow or a subsequent intrusion has not been ascertained. The lower slates stand nearly vertical on Sturgeon River near the gneiss. The following is the general succession within the Huronian, in ascending order: Fine-grained siliceous slates; slate conglomerate, containing profuse syenite and occasional jasper pebbles; limestone; slate conglomerate, like the first; green siliceous chloritic slate; close-grained quartzite of various colors, running into a conglomerate, the pebbles of which include white quartz and red and green jasper. The thickness of the Huronian is calculated at 10,000 feet and corresponds with the determination of the thickness of the quartz-rock series on Spanish River.

Logan,[11] in 1858, applies the term Huronian to the copper-bearing rocks of Lake Huron. A limestone near the middle of the series is used to trace out the structure.

Murray,[12] in 1858, gives a continuation of his study of the rocks north of Lake Huron. He places the rocks of French River, described in the report of 1857, as Laurentian. A belt of limestone 200 feet thick is used in working out the structure of the Huronian. The Huronian is also called the copper-bearing rocks.

Logan,[13] in 1858, gives a general description of the pre-Silurian Azoic rocks of Canada, which occupy nearly a quarter of a million square miles. These are a series of very ancient sedimentary deposits in an altered position. They are of great thickness and are capable of division into stratigraphical groups. In the formation about Lake Temiscaming are sandstones, quartzose, conglomerates, and slate conglomerates, the slate conglomerates holding pebbles and bowlders derived from the subjacent gneiss. The bowlders display red feldspar, translucent quartz, green hornblende, and black mica, arranged in parallel layers, which present directions accordant with the attitude in which the bowlders were accidentally inclosed. From this it is evident that the slate conglomerate was not deposited until the subjacent formation had been converted into gneiss, and very probably greatly disturbed; for while the dip of the gneiss, up to the immediate vicinity of the slate conglomerates, was usually at high angles, that of the latter did not exceed 9°. A similar set of clastic rocks is found on the north shore of Lake Huron, except that the series is here intersected and interstratified with greenstone trap, and pebbles of syenite and jasper are found. Eastward of Lake Temiscamang, in an area of 200,000 square miles imperfectly examined, no similar series of rocks has been met with. Because this clastic series of rocks occurs in typical development on Lake Huron it has been decided to designate it by the term Huronian.

MURRAY,[14] in 1859, in continuing his study of the Huronian, gives most of his time to the region adjacent to the Thessalon and Mississagui rivers. The Huronian is found to be in two main troughs, and the thickness of the series of formations amounts to 16,700 feet. This thickness, greater than that given in the report of 1857, is due to the accidental existence here of intercalated greenstones.

BIGSBY,[15] in 1862, concludes that the Huronian is greatly older than the Cambrian, because of: (1) Its marked similarity, lithologically, to the fundamental gneiss formation. (2) The conformity of these two sets of beds. (3) The great interval of time which must have elapsed between the periods of laying down the fundamental formation and the Silurian, if we are to judge from the occasionally vast thickness of the Cambrian. Beyond all comparison, the Huronian is more widespread and extensive, as well as more uniform in its mineral constitution, than the Cambrian group. It is, perhaps, also more important economically.

LOGAN,[16] in 1863, gives a general summary of the information as to the Huronian series north of Lake Huron. This area is mapped in detail. It extends along the entire North Channel of Lake Huron, with the exception of a short distance where the Laurentian occupies the shore. The full section on the north shore of Lake Huron is as follows, from the bottom upward: (1) Gray quartzite, 500 feet; (2) green chlorite slate, 2,000 feet; (3) white quartzite, 1,000 feet; (4) lower slate conglomerate, 1,280 feet; (5) limestone, 300 feet; (6) upper slate conglomerate, 3,000 feet; (7) red quartzite, 2,300 feet; (8) red jasper conglomerate, 2,150 feet; (9) white quartzite, 2,970 feet; (10) yellow chert and limestone, 400 feet; (11) white quartzite, 1,500 feet; (12) yellowish chert and impure limestone, 200 feet; (13) white quartzite, 400 feet; total thickness, 18,000 feet. Interstratified with certain of these layers, and particularly Nos. 4, 6, 7, 8, and 9, are considerable masses of greenstone. That these are contemporaneous overflows in places is indicated by the fact that they are amygdaloidal and are arranged in layers. There are also present, however, intrusive masses of greenstone and granite, which in the form of dikes cut the stratified rocks in many directions. The different sets of dikes are of at least three different ages, the granite being intermediate in age between two greenstone eruptions. Many of the pebbles of the red jasper conglomerate are banded, showing their derivation from a more ancient stratified rock. South of Lake Pakowagaming is a considerable area of granite which breaks through and disturbs the

Laurentian gneiss, and from which emanates a complexity of dikes, the whole being supposed to be of Huronian age. The immediate contact of the gneiss with the overlying rocks has not been observed. The gneiss between Mississagui and St. Marys rivers has been much disturbed by intrusive granite and greenstone, and it is difficult to make out how the stratified portions are related to one another. Near Les Grandes Sables a gray quartzite, supposed to be the lowest Huronian, abuts against one mass of gneiss, and runs under another and appears to be much broken by and entangled among the intrusive rock. On Lake Temiscamang the Laurentian gneiss is followed by a slate conglomerate which contains pebbles and bowlders, sometimes a foot in diameter, of the subjacent gneiss. The Huronian of Lake Huron is correlated with the lower copper-bearing rocks of Lake Superior. Several detailed sections are described. The general sections represent the Huronian series as resting unconformably upon the Laurentian.

LOGAN,[17] in 1865, states that the horizontal strata which form the base of the Lower Silurian in western Canada rest upon the upturned edges of the Huronian series, which in its turn unconformably overlies the Lower Laurentian. The Huronian is believed to be more recent than the Upper Laurentian series, although the two formations have never yet been seen in contact.

BELL,[18] in 1878, reports on geological researches north of Lake Huron and east of Lake Superior, including Lake Nipissing. He finds the rocks along the whole northeast coast of Georgian Bay, a distance of 125 miles, to belong to the Laurentian series. They consist principally of varieties of gneiss, occasionally interstratified with bands of hornblendic and micaceous schists. The crystalline limestones are also found, as well as stratified diorites, trap rocks, and granite veins. The rocks have no uniform strike and are contorted into many anticlines and synclines. The crystalline limestones of Georgian Bay and Lake Nipissing are regarded as belonging in three and possibly more crystalline bands. Associated with the limestone are sometimes found chert, conglomerate, quartzite, and magnetic iron ore. A junction of the granite with the Huronian quartzite and hornblende schist is mentioned.

SELWYN,[19] in 1884, west of Wahnahpitae River, on the Canadian Pacific Railway, for 80 miles finds Laurentian rocks, which consist of felsites or felsitic quartzites, thin-bedded quartzites which hold angular fragments of granite and gneiss, diorite, and diabase, with a series of coarse and fine fragmental beds varying in character from a fine ash to coarse agglomerate.

IRVING,[20] in 1887, summarizes the information of the Canadian Survey with reference to the Huronian of Lake Huron, and describes a contact near Thessalon River between the underlying gneissic series and the overlying Huronian. Here a basal conglomerate, containing partly rounded and angular fragments up to 2 feet in diameter, largely derived from the immediately underlying gneiss, rests directly upon the upturned edges of the gneissic series. Such a contact indicates a great structural break, whether the underlying gneissic series is of eruptive or of sedimentary origin. If sedimentary, it must have been metamorphosed to its present crystalline condition and upturned before the fragmentals were deposited upon it; if eruptive, its coarsely crystalline character shows that it belongs to the deep-seated rocks which must have crystallized at great depth, and therefore that it must have been subjected to profound erosion in order to appear at the surface. Such a contact is also found at two or three other points on the Algoma branch of the Canadian Pacific Railway, and particularly near the mouth of Serpent River. Logan's[a] green chloritic slate is composed of diabase sheets and a little interleaved fragmental material, perhaps partly volcanic ash.

Winchell (N. H.),[21] in 1888, describes many localities within the Original Huronian. Logan's chloritic slates, as well as the greenstones, are regarded as accidental features, the former being a part of the basic eruptive rocks of the region. Vast outflows of greenstone cover many square miles in the Thessalon Valley and constitute hill ranges as conspicuous as those of any hill rock in the region. This series is classified and parallelized with the Minnesota rocks, as follows:

Original Huronian.	Minnesota equivalents.
Otter Tail quartzite Thessalon quartzite	Pewabic quartzite (?) New Ulm, Pokegama and Wauswaugoning quartzites.
Black slate	Animikie black slate.
"Lithographic stone" and fine gray quartzite	Not known.
Red felsite	Felsites at Duluth and probably the Great Palisades.
Mississagui quartzite	Not known.
Slate conglomerate	Ogishki conglomerate.

Chert and quartzite pebbles in the Thessalon quartzite lead to the inference that this is unconformably upon the black slate. The existence of granite bowlders in the slate conglomerate indicates another unconformity between it and the granites of the region. In this latter case the evidence is conclusive, and in the former it is inconsiderable.

Winchell (Alexander),[22] in 1888, makes further observations upon the Original Huronian. In the Huronian system is a large volume of eruptive rock, with a great thickness of rocks of undoubted sedimentary origin, and an equal volume of an obscure slaty char-

[a] See note 2, Chapter V, p. 482.

acter. The latter appear to constitute the green chlorite schist of Logan, which is either an ancient or much altered eruptive or highly altered sedimentary material. The quartzites contain angular fragments of such a character that they seem to be derived from this diabase schist; and this circumstance countenances the theory that the latter are older and probably sedimentary in origin. The Huronian of Canada is as follows in descending order: Otter Tail white quartzite, 4,000 feet; Thessalon red and gray quartzite, 5,000 feet; Otter Tail cherty limestone, 100 feet; Upper Plummer conglomeratic and siliceous argillite, 500 feet; red felsite, granulite, and quartzite, 100 feet; lower conglomeratic and siliceous argillite, 7,400 feet; Bruce limestone, 100 feet; Mississagui vitreous quartzite, 3,750 feet. This succession includes neither the lower nor the upper limit of the Huronian. At St. Josephs Island the Huronian is immediately overlain by a fossiliferous limestone, apparently the Chazy. It thus appears that the Huronian is a system immediately below the Lower Silurian, and that if no intervening terranes are wanting it occupies the position of the Taconic of Emmons and the Lower Cambrian of Sedgwick. The lower limit of the Huronian must be succeeded by a formation of vitreous quartz, red jasper, and graywacke, besides greenstones, red granulite, red gneiss, and mica-bearing granite, since fragments of all these are found in the Huronian. It may be that the quartzite pebbles are derived from the Mississagui quartzite, but the red jasper and greywacke must have been derived from a terrane older than the Huronian and newer than the crystalline masses of the Laurentian.

Bonney,[23] in 1888, discusses the development of the crystalline schists in the neighborhood of Sudbury. The semicrystallines can be easily separated from the thoroughly crystalline rocks of the Laurentian. In the Huronian rocks two groups may be distinguished, one of which is slightly altered and the other very much more extensively modified. The semicrystallines are compared with those of like character in Great Britain.

Barlow,[24] in 1890, describes the relations between the Huronian and the Laurentian north of Lake Huron. At many localities the contact is found to be an irruptive one, the granite and gneiss intruding the Huronian clastics. Very often the Huronian strata dip into or under the gneiss, although often the Huronian beds are superimposed upon the gneiss in perfect conformity, and occasionally gneiss is seen dipping away from the vertical Huronian strata. Huronian rocks are also seen resting unconformably upon the upturned edges of Laurentian gneiss. The Huronian strata are often metamorphosed where in contact with the gneiss. These different phenomena are all explained by the later irruptive character of the gneiss. It is concluded that the Huronian system is the oldest series of sedimentary strata known in this region.

Bell,[25] in 1890, states that stretching from Lake Huron to Lake Temiscamang is the greatest area of Huronian rocks in Canada. The most prevalent rock in this region is graywacke, often conglomeratic. Another rock of great abundance is a quartz diorite. These two are the parent rocks of the Huronian. The quartzites and clay slates are but phases of the graywacke. The rocks of this region show three ways by which gneiss may be formed—by direct conversion of the thin-bedded or slaty varieties of graywacke, by alteration of the mixed quartz and feldspar rock derived from other varieties of it, and by alteration of the modified quartz diorites. The dolomites are of a concretionary or segregated nature, derived from the hornblende and augite of the rocks with which they are associated. During the process of conversion from graywacke into syenite, strings and veins of magnetite have formed.

Winchell (Alexander),[26] in 1890, gives further observations on the Original Huronian region. Northwest of Echo Lake is found a series of argillites, slates, quartzites, and schists, which are frequently conglomeratic and in one place contain outcrops of hematite. These strata have a nearly vertical attitude, strike nearly east-west, and resemble the Knife Lake series and Ogishki conglomerates of Minnesota. These rocks can not belong to the same system as the quartzites, upper slate conglomerates, and limestone of the Huronian, which dip at an angle of 20°. There is here a genuine discordance of stratification, and two series, not one, as mapped by Logan. The lower system is the formation which occurs at Gros Cap, Goulais Bay, and Dore River, which was identified by Logan with the Huronian of Lake Huron. The author is convinced also of their identity with the vertical strata in Minnesota and Canada known as the Keewatin system. It is also clear that these gnarled, green pebble slates are the prolongation of the lower slate conglomerate of the Thessalon Valley.

Winchell (Alexander),[27] in 1891, maintains that the Original Huronian is divisible into two unconformable series, the break occurring between the upper and lower slate conglomerates, and the intervening limestone belonging with the upper series. The descriptions of this region by Murray indicate that near Lake Wahnapitae there is a stratigraphic unconformity between the upper and lower divisions of the Original Huronian, as here the slate conglomerates are in a nearly vertical attitude, while the newer members seldom have an inclination greater than 45°. In every instance in which the lower slate conglomerate has been traced by Logan or Murray to the proximity of the gneiss these formations seem to be conformable in position, though the actual juxtaposition was concealed. At Murray Hill the slate conglomerate has a dip of 78° S., while 2 miles south of this it has a dip of 40° S. 30° W. The first is regarded as the lower slate conglomerate and the second as the upper slate conglomerate. At the junction of the Sudbury branch of the Canadian Pacific Railway with Vermilion River an arenaceous slaty rock, having a dip 45°, rests on a different schist having a different dip. At this locality, according to Lawson, the unconformity is similar to that at Penokee Gap, Wisconsin. The lower rock is a fine micaceous gneiss or mica schist, and the upper rock is interbedded quartzite and gray argillite. At Echo Lake is the following series, in descending order: Slate conglomerate and quartzite, with a dip of about 20°; after this is an interval of a third of a mile, and then appears a quartzose slate conglomerate comparable with the Ogishki conglomerate; this is followed by quartzite, and this by alternations of quartzite, quartz schist, and various slates, schists, and argillites, the series having a dip of 75° to 80° SW., and being as a whole more crystalline than the upper system. It is concluded that the name Huronian must be restricted to the upper or lower system; and if restricted to the upper system it remains attached to the best known and most characteristic portion of the old complex Huronian. For the older system, not distinctly named Keewatin by Lawson until 1886, the term Kewatian is proposed.

Bell,[28] in 1891, describes the geology of the district of Sudbury. The main outlines of the great Huronian area of this region are given. Within the region are many inliers of gneiss and red quartz syenite, which correspond with Laurentian types of rock, and it is uncertain whether they are protrusions of the older rocks from beneath or whether some of them may not be portions of the Huronian itself which have undergone further metamorphism. In the Sudbury district many of the areas consist of separate masses, like large and small bowlders, the interspaces being filled by a breccia with a dioritic paste, suggesting that these rocks may be underlain at no great depth by diorite which was in a soft condition after the gneiss and syenite had been consolidated. At some places within the syenite area, as, for example, about 2 miles west of Cartier, a massive fine-grained rock like some varieties of graywacke may be seen passing into thoroughly crystalline quartz syenite. The rocks in greatest quantity, and those which constitute the lowest member of the Huronian series between Lakes Huron and Wahnapitae, are quartzose graywackes and quartzites, with occasionally a little felsite. In this member of the series crystalline diorites occur as intruded masses, varying from a half mile to 10 miles in length; associated are obscurely stratified varieties of quartz diorite and of dioritic and hornblende schists, and also compact brown-weathering dolomite. The next member of the series in ascending order is a black volcanic glass breccia consisting of angular fragments crowded together. The highest rocks of the series, or those which occupy the center of the trough, are evenly bedded argillaceous sandstones or graywackes, interstratified with slaty belts and overlain at the summit by black slates. The stratified Huronian rocks, as well as the gneiss and quartz syenite, are traversed by dikes of coarsely crystalline diabase, which are often large and can be traced for considerable distances.

WINCHELL (N. H.),[29] in 1891, gives further observations upon the Huronian. Northwest of Sudbury and eastward from Algoma there are two formations. In both, the slate and slate conglomerate constitute the upper formation. In the Sudbury region the underlying rocks are largely felsitic, but are also occasionally micaceous and hornblendic. In the section eastward from Algoma the underlying formation seems to be the Mississagui quartzite, with interbedded green fissile schist, the mica schist varying into hornblende schist. Logan's Mississagui quartzite is supposed not to be Logan's lowest gray quartzite, but is probably a constituent part of the Keewatin. It is concluded that the observations confirm, or at least do not contravene, the conclusion that the Huronian system of the Canadian reports embraces two or three formations, one of these being the true Huronian first described and mapped by Murray, another the Keewatin of Lawson, and another the series of crystalline schists styled the Vermilion series.

PUMPELLY and VAN HISE, [30] in 1892, describe the relations of the Huronian and Laurentian, and also give evidence for the divisibility of the Huronian into two series as advocated by Winchell.

In reference to the latter point, at a limestone quarry about 2 miles northeast of Garden River the upper slate conglomerate was found in actual contact with the limestone member. This conglomerate has a rough appearance of stratification and bears numerous fragments of limestone, many of them more than a foot in length and all in precisely the condition in which the original limestone is now. In this conglomerate are also numerous fragments of schist and granite. The line of contact could be traced only a short distance, and it appears to follow somewhat closely the lamination of the limestone. These relations clearly indicate that after the limestone was deposited, before the beginning of the time of the upper slate conglomerate, there was a considerable interval of erosion. The observations thus tend to confirm Winchell's conclusion that the Laurentian is divisible into two discordant series, the break occurring above the lower limestone. If this break shall prove to be general at this horizon, it places in the Lower Huronian, using Logan's thicknesses for the formations, about 5,000 feet, and in the Upper Huronian about 13,000 feet.

Almost immediately below the limestone was found the lower slate conglomerate, which in lithological character is precisely like the slate conglomerate in contact with the granite below described.

As bearing upon the relations of the Huronian and Laurentian, one new locality was found, and the contact described by Irving east of Thessalon was again examined. About 2 miles northwest of Garden River the lower slate conglomerate of Logan was traced downward into a finely laminated semicrystalline quartzose schist, and this downward into a basal conglomerate and recomposed granite which rests almost directly upon the solid granite. The major part of the débris of the basal bowlder conglomerate is derived from the immediately subjacent granite. The evidence of erosive unconformability is thus of the clearest character. The likeness of the slate conglomerate at this locality to that below the limestone, the metamorphosed character of the quartzose schist, and the steepness of the inclination of the rocks all bear toward the correctness of Logan's mapping of this slate conglomerate as the lower one, and, if it is, the unconformable contact is between the lower series of the Huronian and the granite.

At the contact between the lower quartzite of Logan and the Laurentian east of Thessalon, described by Irving, it was found that the relations could be much more clearly seen than at the time the locality was visited by Irving, because then the water was very high and two islands upon which the contact occurs were submerged. The Laurentian area does not consist of simply granite or gneiss, as might be inferred from Logan's mapping, but is an intricate complex of granite, gneiss, and schist. The granite has intruded the schist and fine-grained gneisses in the most intricate manner. In many places large roundish fragments of schist or gneiss are contained in granite, and these have a decidedly waterworn appearance. However, in any given area the fragments are always of material identical with that of the adjacent gneiss or schist. In short, the rocks furnish one of the most beautiful illustrations of the relations described by Lawson between schists and gneisses and a later intrusive granite. Resting upon this complex was found a great bowlder conglomerate which differs radically in character from the pseudo-conglomerates of the Laurentian. The pebbles and bowlders instead of being widely separated are packed closely together. Within a very small area, a square yard or square rod, may be found all varieties of the material occurring within the Basement Complex—that is, many phases of crystalline schist, gneiss, granite, and granite gneiss. On one of the islands in which the contact was seen the line of separation is perfectly sharp and irregular, bending at one place at an angle of 50°. Also the foliation of the granite gneisses abuts almost at right angles against the line of contact at one place. The contact here, then, has all the characteristics of one of erosive unconformability. Upon the second island, instead of a clear line of contact between the conglomerate and the Basement Complex, there is an apparent gradation, the change occurring within 5 or 6 feet. Here the solid granite gneiss is first broken; then in passing upward the angular fragments have moved somewhat; in passing still farther upward they become roundish and are mingled with extraneous material, until a bowlder conglomerate is reached which is in every respect like that before described. This relation is not uncommon when an encroaching shore line overrides a rock formation.

It is concluded that between the lowest members of the Original Huronian series and the granite-gneiss-schist Basement Complex which Logan has called Laurentian there is the clearest evidence of a very great unconformity; also, that the Laurentian series, instead of being a simple one, consists of rocks of many different kinds and has a most complex history.

Bell,[31] in 1891, reports on the Sudbury mining district. The rocks are divided into three groups, in ascending order: (1) A gneiss and hornblende granite series—Laurentian. (2) A series comprising quartzites, massive graywackes, often holding rounded and angular fragments; slaty graywackes, with and without included fragments; drab and dark-gray argillites and clay slates; dioritic, hornblendic, sericitic, felsitic, micaceous, and other schists; and occasionally dolomites, together with large included masses or areas of pyritiferous greenstones. This group constitutes the ordinary Huronian of the district. (3) A division consisting of a thick band of dark-colored siliceous volcanic breccia and black slate (generally coarse), overlain by drab and dark-gray argillaceous and nearly black, gritty sandstones and shaly bands. The breccia is underlain in places by quartzite conglomerate. (4) In addition to these, dikes of diabase and gabbro cut through all the foregoing, and are, therefore, newer than any of them, although they may not belong to a later geological period.

Flanking the Huronian rocks on the southeast is gneiss, and on the northwest a mixture of gneiss and hornblende granite. The first of these rocks is of the characteristic Laurentian type, but the hornblende granite and quartz syenite on the northwest are not always characteristic of the Laurentian. These rocks, however, pass into the gneiss in such a way, and are so mingled with them on both a large and a small scale, that it was impossible to separate them. Within the Huronian trough, and parallel with it, is also a tongue of gneiss and hornblende granite 2 or 3 miles wide and 39 miles long.

The Huronian division forms a part of the great Huronian belt extending from Lake Superior and Lake Huron nearly to Lake Mittassini. The bedding of the Huronian is usually nearly vertical, or stands at high angles. Occasionally the rocks have been sheared by pressure. Graywacke conglomerate, in places full of rounded pebbles of gray quartz syenite, is found on the Blue River branch of Spanish

River, Lot 2, Conn. III. In the township of Hyman is an augen gneiss which is evidently a metamorphosed clastic, as it forms a part of the quartzite and graywacke series. The line of junction between the Laurentian and the Huronian is unusually straight. West of Lake Wahnapitae, along the contact, there is evidence of great disturbance and crushing, the rocks of the two series being much broken up and intermixed. It is not improbable that at the junction line is a considerable fault.

The third division is less altered, and is in a distinct basin running from the township of Trill northeastward to near the South Bay of Lake Wahnapitae, a distance of 36 miles, with a breadth of 8 miles in its central portion. These rocks are perhaps unconformable to the older Huronian rocks on which they rest, and may be Upper Huronian, or possibly lower Cambrian.

Along Onaping Lake and River and Straight Lake are Huronian outliers. The principal kinds of rocks in the first basin are slate conglomerates, with well-rounded pebbles and bowlders, mostly of binary granite, quartz, quartzite, and schists; and coarse arenaceous or graywacke conglomerate, together with some pale-pink quartzites and bluish and greenish-gray felsites, argillites, and slates. The principal rocks of the second basin are graywacke schists, quartzites, quartzite or graywacke conglomerates, green schists, hard sandstones, greenstones, and some dolomites. In the conglomerates are pebbles of graywacke and hornblende granites like the prevailing varieties found in situ in the region, black slates, and black and white quartz. On Lot 4, Con. III, Moncrieff, is the junction of the Laurentian red hornblende granite and the graywacke.

It is concluded that the Huronian rocks of the Sudbury district are largely of volcanic nature, although many of them have been rearranged by water; hence they may be termed pyroclastic. The graywackes consist of granite débris more or less comminuted by the modifying action of water. Under this name are included many varieties of rocks, ranging from those which approach quartzites to others approaching argillites. The largest fragments are usually of red or gray aplite. As a general rule the different divisions of the Huronian rocks do not maintain their thickness very far on the strike, but diminish more or less rapidly, their place at the same time being filled by a corresponding thickening of other members of the series.

The trappean rocks of the district consist of (1) extensive masses, together with many of smaller size, incorporated with the other Huronian rocks, and probably contemporaneous with them; and (2) dikes which cut through all the members of the series. There are nearly 50 areas of diorite, two principal belts of diabase, and a belt of slaty, greenish diorite, which in places becomes brecciated and includes fragments, from large bowlders down to small pebbles, consisting principally of quartzites, granites, and syenites.

Very numerous details are given, which can not be summarized.

WILLIAMS,[32] in 1891, gives microscopical notes on various rocks from the Sudbury district. The sedimentary rocks are found to include those which are plainly clastic, those which are clastic but partially recrystallized, and those which are highly crystalline but probably derived from clastics. In the last division are placed felsite, gneiss conglomerate, and gneiss. The eruptives, including various acidic and basic deep-seated and surface rocks, also show extensive metamorphism and recrystallization. Placed among the highly crystalline rock, probably derived from the clastics, are certain felsites, gneiss conglomerates, and gneisses. Certain granites, gneisses, and schists are of uncertain origin, but give no indication of clastic derivation.

BELL,[33] in 1892, gives a general account of the Laurentian and Huronian systems, and a sketch of the geology of the country extending from Lake Huron northward to Lake Temiscaming and from Lake Nipissing westward to Spanish River. The Laurentian system is divided into an upper and a lower formation. The latter consists almost entirely of fundamental gneiss, while the upper Laurentian appears to consist of metamorphosed and sedimentary strata, to some extent, at least.

The lower division of the Laurentian consists of red and gray gneiss, usually much bent or disturbed, and having generally a rudely foliated structure and a solid or massive character. The feldspar is almost entirely orthoclase. The upper division of the Laurentian is more complex. It possesses more regularity in stratification and includes great banded masses of crystalline limestones, vitreous quartzites, mica schist and hornblende schist, massive pyroxene, and massive and foliated labradorite rocks. Considerable areas of granite and syenite occur in the formation. The Upper Laurentian of the Ottawa Valley may be roughly estimated at 50,000 to 100,000 feet in thickness.

While the older Laurentian rocks afford no proof of the permanent existence of the sea upon the earth, water appears to have been present, perhaps only as precipitations upon the surface, at every stage of its formation. But the deposits of limestone and tolerably pure silica in distinct bands in the Upper Laurentian afford strong support to the aqueous theory of its deposition.

With the beginning of the Huronian period great volcanic activity began, and there is evidence of the permanent abode of water on the surface of the earth. The general character of the Huronian rocks may be said to be pyroclastic, by this signifying that, although fragmental, they have nevertheless had an igneous origin.

The area mapped between the Huronian belt and the shore of Georgian Bay appears to belong to the Upper Laurentian. The rocks are gneisses of the typical Laurentian varieties, finely stratified and regularly arranged in anticlinal and synclinal folds, the angles of dip usually not being far from 45°, but lesser and greater dips being found. Red and gray varieties are in about equal proportion, and they alternate with each other in thick and thin sheets. Mica gneisses are predominant. No beds of crystalline limestone are found west of Iron Island in Lake Nipissing. Limestones are associated with the gneisses on some of the islands of the eastern part of this lake and at Lake Talon on the Mattawa. In the Parry Sound district are five distinct bands of Laurentian limestone. These rocks are classified with the Upper Laurentian rocks of the counties of Ottawa and Argenteuil.

The Laurentian rocks northwest of the Huronian belt are heavy contorted gneisses of the Lower Laurentian. Associated with the gneisses are red granites which are classed with the Laurentian, but which may be really Huronian. These may have formed by softening of the gneiss by heat, combined with recrystallization, or they may be due to the alteration of the Huronian arkoses or graywackes, or they may be mainly eruptive. These granites are along the contact line between the Laurentian and the Huronian. Along the line of contact between the granites and the Huronian quartzites and schists the rocks are much broken. It is not improbable that a fault exists at the line of junction between the Laurentian and Huronian rocks.

The great Huronian belt consists of a large variety of rocks, such as crystalline schists, quartzites, conglomerates, agglomerates, clay slates, greenstones, dolomites, etc., the majority of which are pyroclastic. The rocks are usually tilted at high angles. There are numerous instances where there is a gradual transition from the Huronian to the lower series. A few instances of local want of conformity between the two are no evidence that the two systems are not conformable on a grand scale. The few known instances where there appears to be a want of parallelism are more probably due to faulting. The pyroclastic rocks show the agency of water in their formation, and were largely derived from igneous matter, which had been more or less recently erupted. The newest rock of the Sudbury district is a volcanic breccia, which forms a continuous range of hills for a distance of 36 miles, with a breadth in the center of 8 miles. Within the Huronian rocks are intrusive red granites.

Barlow,[34] in 1892, states that the Huronian system is the oldest sedimentary strata of the north shore of Lake Huron, and that the Laurentian gneiss or Basement Complex is the original crust of the earth or floor on which the first sediments were laid down. This floor, as shown by the pebbles of the Huronian, was granite which had in many places a foliated or gneissic structure. In many places the subsequent folding and fracturing of the comparatively thin crust of the earth has caused large portions of the Huronian to sink below the plane of fusion, the result of which has been to produce irruptive contacts. At other places, as described by Pumpelly and Van Hise, the Basement Complex may have remained undisturbed, so that the overlying detritals have not been intruded by the granitic mass beneath.

Barlow,[35] in 1893, describes the Laurentian granites and gneisses as intrusive in the Huronian rocks north of Lake Huron. The localities described are Killarney Village; Beaver, Fox, Balsam, Three Mile, Brush, Camp, Crooked, Johnny, Panache, Wavy, Chief's, Daisy, Baby, and Alice lakes; Goshen, Broder, and Dell townships; Wahnapitae River; Cartier and Straight Lake stations; and two islands near Thessalon. As evidence of the eruptive nature of the Laurentian gneiss in the Huronian sediments are cited the diverse stratigraphic relations of the rocks along their line of junction; the invariable alteration of the sedimentary rocks along the contact line; the inclusion in the gneiss of angular fragments clearly referable to the adjacent sedimentary strata; the occurrence of gneissic intrusions and apophyses of pegmatite in or laminated with and cutting across the bedding of the Huronian rocks; the absence of sedimentary rocks within the gneiss, and the general character of the gneiss, which, in appearance and behavior, more nearly resembles an eruptive granite than an altered sedimentary rock. It is therefore concluded that the Huronian is the oldest series of sedimentary strata in this region, and that the floor upon which these were laid down must have been subsequently fused and recrystallized.

Bell,[36] in 1894, describes the pre-Paleozoic rocks north of Lake Huron as having been subjected in certain areas to vast denudation and decay before Paleozoic time. The evidence of this decay, most frequently found in granite, consists in hollows, pits, irregular ridges, and even small caverns, which are filled with Paleozoic limestone. These irregularities are regarded as having been formed at the bottom of the deep sea by solution. Had the erosion taken place on land there would be evidence of this in deeper decay in the substances of the rock and in the deposition of detrital deposits below the pure limestone, which in many cases rests directly upon the pre-Paleozoic rocks.

In the area between the foot of Lake Ontario and the head of Georgian Bay the contact of the Potsdam sandstone and Black River limestones with the underlying gneiss and quartzite is seen at many localities. These rocks are generally hard and fresh. The surface is irregular, and the whole has been buried beneath the horizontal Paleozoic rocks.

Many of the long, narrow valleys of the Archean region are due to the decay and removal of wide greenstone dikes, or narrower parallel dikes with the belts of rock between them. The greenstone dikes are never found to traverse the overlying Silurian, and it is supposed that these valleys were mostly formed before the deposition of the Paleozoic strata. It is thought that the larger part of this Archean area never received any of the Paleozoic rocks upon it, and that the surface of the Archean had been reduced to something like its present level and aspect before the Paleozoic deposits were laid down. As evidence of this are regarded outliers of the Potsdam sandstone and Black River limestone filling similar narrow valleys.

Gibson,[37] in 1895, gives a summary, from the reports of the Canadian Geological Survey, of the pre-Cambrian geology of the Hinterland of Ontario.

Blue,[38] in 1896, sketches the geological history of the New Ontario, which includes that part of the province of Ontario lying beyond Matawan and French rivers and Nipissing, Huron, and Superior lakes to the north and west boundaries of the province. Laurentian and Huronian rocks form highlands which in Archean time were the most important physical feature of North America, sweeping in a curve through what is known in our time as the regions of Labrador, Quebec, Ontario, and the Northwest Territories. While there are large areas in which eruptive masses of granite and gneiss have penetrated the Huronian rocks and thrown them into folds, proving their later age, in general the reverse is the case, the Huronian resting unconformably upon the Laurentian and being of later origin. The Huronian is overlain unconformably by Cambrian rocks, under the Cambrian being included Animikie, Nipigon, and Potsdam rocks.

Bell,[39] in 1898, reports on the geology of the area of the French River sheet, which represents the country around the north end of Georgian Bay. Huronian rocks occupy the northwest corner of the area and Laurentian rocks all the rest to the southeast.

The Laurentian rocks in general resemble the Grenville series, which belongs to the upper division of the Laurentian. They consist of red and gray mica and hornblende gneisses, in beds which can be traced with regularity for considerable distances, together with coarse hornblende and mica schists and bands of quartz rock with schistose partings. No limestones have yet been found among those rocks within the boundaries of this area, but in the Parry Sound district, to the east, among similar strata, the writer has traced five bands of crystalline limestone like those of the Grenville series. The gneisses are distinctively stratified and regularly arranged in anticlinal and synclinal forms, according to the structural laws governing stratified rocks; the average angles of dip are not steep, and in general, so far as their texture is concerned, the gneisses have the characters of altered sedimentary deposits. Cutting the granites are greenstone dikes, with an east-west direction.

The Laurentian rocks northwest of the Huronian area, outside of the area of the sheet, are considered to belong to the older division of the system.

The Huronian rocks comprise quartzites, sericite, chlorite, hornblende, and arkose schists, clay slates, graywackes, and dolomites. They have a general synclinal structure. The quartzites of the ridges northwest of Killarney form the southern side of the basin and those of the Cloche Mountains the northern side. Along the southern side of the major syncline are several subordinate folds. Associated greenstones are less conspicuous than in the Huronian rocks of the Sudbury area to the north. Those present are more largely developed in the tract on the south side of Lake Pañache than elsewhere.

In the space between the Cloche Mountains and the range which runs eastward from McGregor Point to Sturgeon Lake, including Bay of Islands, McGregor Bay, and the land thence eastward to the junction of the two chains, the rocks belong to a local division of the Huronian, which may, for present convenience, be called the arkose series with its associated rocks. Structurally this area would appear to occupy the central part of the synclinal area between the abovementioned conspicuous quartzite ranges. Although various forms of arkose or graywacke are the prevailing rocks within this space, there are in different parts of it considerable quantities of gray quartzites and fine quartz conglomerates, mixed agglomerates and breccias, sericitic and micaceous schists, impure dolomites, and eruptive greenstones.

As to the origin of these rocks, the thick unstratified and brecciated graywacke or arkose may represent consolidated masses of volcanic ashes or mud with stones, which were thrown upon the land or into shallow water, while the stratified varieties may have consisted of similar ejectamenta thrown into deeper water, where they became arranged in layers as we find them. Some of these rocks, whether stratified or otherwise, may represent volcanic products which were originally thrown into the sea in a molten or heated condition and became broken up and almost completely disintegrated.

A study of the different phases of the graywackes and their associated rocks in this region would appear to prove that the former constituted the crude material from which both the quartzites and the clay slates were derived by the modifying and separating action of water. Again, by the action of time, pressure, heat, and other metamorphosing agents upon different varieties of graywacke, some of our granites, syenites, gneisses, and possibly other crystalline rocks were probably formed.

Solid and slaty argyllites are found along Long Lake, an expansion of Whitefish River, and slate conglomerates occur on both sides of Bear Lake and between Cat and Leech lakes. However, these rocks do not form a large proportion of the Huronian series in this district.

Impure magnesium limestones occur in the northern part of the Bay of Islands, in the northwestern part of the township of Rutherford, and north of the area of the sheet, near Lake Panache.

Between the Huronian rocks on the north and the Laurentian rocks on the southeast there is a belt of red granite, the Killarney belt, running from Badgely Island to Threemile Lake. This granite is apparently of eruptive origin and of later age than the quartzites. All along the line of contact with the Huronian the rocks give evidence of great disturbance. Huge portions, as well as many of moderate size, have been separated from both sides and have been mingled together and intermixed with finer débris, all being cemented into a coarse breccia.

The southeastern side of the Killarney belt of granite rests against the Laurentian gneiss, except in the interval from the southern point of George Island to the entrance of Collins Inlet, where a narrow belt of partially altered, fine-grained, brittle, red and sometimes gray quartzite intervenes between the granite and the water of Georgian Bay. Farther northeastward, or where the granite of the Killarney belt comes in contact with the gneiss which prevails to the east, it is not always separated from the latter by a very distinct boundary. The rocks in some places pass into each other more or less gradually.

Burwash,[40] in 1897, during the survey of the boundary line between the districts of Nipissing and Algoma in Canada, takes geological notes of the area traversed.

The run was made from south to north, from the upper waters of the Vermilion and Wahnipitae rivers to within 35 miles of Lake Abittibi, and, with the exception of two areas of eruptive granite, the country was found to be underlain for the entire distance by Huronian rocks. The section is given in detail.

Walker,[41] in 1897, describes the stratigraphy and petrology of the Sudbury nickel district of Canada. The oldest rocks of the district are gneisses of various kinds, which are regarded as of Laurentian age. Next in age to the gneisses is a belt of rocks consisting of quartzite, graywacke, amphibolite, mica schist, phyllite, clay slate, and altered volcanic breccia, which extends from the north shore of Lake Huron northeastward to Lake Mistassini, in the neighborhood of Sudbury, the belt being about 25 miles wide. The rocks of this belt are believed to be of Huronian age. The Huronian rocks have suffered severe metamorphism, and the original character of many of them can not be made out. In and adjoining the Huronian belt are elliptical areas of later eruptive greenstone, in places intimately associated with and genetically inseparable from gneissoid and micropegmatitic granites. The nickel ore, principally pyrrhotite, occurs intimately intermingled with the eruptives, and is regarded as a concentration by differentiation from the eruptive magma. Cutting both the Huronian and the included nickel-bearing eruptives are masses of fine-grained pinkish biotite granite, sending apophyses into the surrounding rocks. This granite is found to have been intruded in two eruptions. The youngest rocks of the Sudbury district are olivine diabases, which occur in dikes, cutting all the other rocks of the district.

Barlow and Ferrier,[42] in 1898, discuss the relations and the structure of certain granites and associated arkoses on Lake Temiscaming. An examination of the contact of the granite and arkose shows a gradual and distinct passage of the granite into the arkose. Microscopically also there may be seen evidence of the decomposition of the feldspars of the granite, the breaking up of the feldspar and quartz, and finally the rearrangement and assortment of the material by water, indicating a gradual transition from the granite to the arkose.

The arkose is regarded as a Huronian sediment derived from and deposited on the granite. This is regarded as the only instance at present known in which the material composing the Huronian clastics can be clearly and directly traced, both macroscopically and microscopically, to the original source from which it has been derived.

Ells,[42a] in 1907, gives a summary account of the geology of New Brunswick. A comparison of the nomenclature and classification of Bailey and Matthew in 1870–71 with that of Ells in 1907 is as follows:

1870–71.	1907.
Laurentian	Pre-Cambrian, in part igneous and in part altered Silurian and Devonian.
Huronian: Kingston, Coldbrook, Coastal	Pre-Cambrian with associated igneous masses.
Cambrian, St. John group	Cambrian, Etcheminian, division 0 at base, Cambrian divisions 1, 2, and 3.

Barlow,[43] in 1899, describes the geology of the area of the Nipissing-Temiscaming map sheets, comprising portions of the district of Nipissing, Ontario, and the county of Pontiac, Quebec.

Laurentian and Huronian rocks occupy most of the area. These do not include a few small isolated inliers of crystalline limestone and gneissic rocks which resemble the Grenville rocks to the south and southwest. These are so small in quantity that they are not mapped. Their relations to the Huronian are not discussed.

The Laurentian rocks occupy two-thirds of the area of the two sheets. While probably representing in part the first-formed crust of the earth, and therefore the basement upon which the Huronian rocks were laid down, the Laurentian has undergone successive fusions and recementations before reaching its present condition. It is now a complex of plutonic rocks which, in general, show irruptive relations to the overlying Huronian series. However, on Lake Temiscaming the Laurentian is unconformably below, and in direct contact with, an arkose of Huronian age, which has apparently been derived from the disintegration of the Laurentian granite.

The Huronian occupies about a third of the combined area of the two sheets. It is separable into three divisions, in ascending order as follows: (1) Breccia or breccia conglomerate, (2) graywacke shale or slate, and (3) feldspathic sandstone or quartzite. The maximum thickness of the first division is 600 feet; of the second, 100 feet; and of the third, 1,100 feet. Associated with these clastic rocks are various rocks of igneous origin, including deep-seated diabase and gabbro and volcanic ejectamenta.

COLEMAN, in 1899 and 1901, discusses the general geology of this region, together with that of the north shore of Lake Superior. See summary in Chapter III, section 4, Lake Superior region, pages 285–289.

MILLER,[44] in 1901, describes the iron ores and associated rocks of the area adjacent to Lake Temagami and of the Lake Wahnapitae and Hutton areas to the west, all in the Nipissing district of Ontario. The Temagami area has been previously mapped and reported upon by A. E. Barlow.[a] Miller's discussion of the general geology of this area follows that of Barlow, with minor additions and corrections.

MILLER,[45] in 1902, publishes geological notes taken on a canoe trip from Lake Temiscaming northward to the Height of Land. Special attention was paid to the occurrence of minerals of commercial value, and no mapping is attempted. He finds various kinds of igneous rocks, both plutonic and volcanic, such as granite, syenite, diorite, olivine diabase, quartz porphyry, and others of less importance. In addition to these most of the metamorphic fragmental rocks characteristic of the Huronian occur, among which may be mentioned quartzite, slate graywacke, and different varieties of the pyroclastic series, ash rocks, and agglomerates. The popular belief that the Height of Land in this district represents the highest point of the surface from which sediment was derived for the formation of deposits of different ages which lie to the south is scarcely based on fact. He found what appear to be thick deposits of Huronian conglomerate and other water-formed material resting on the surface close to the Height of Land. It is evident from this that the surface level must have changed considerably since Huronian times, and that what is now the Height of Land may have once been a comparatively low-lying area.

VAN HISE and SEAMAN,[46] in 1902, examined the contact of the series of slates and graywackes called by Bell Cambrian, but believed by Van Hise and Seaman to be Upper Huronian, with the Laurentian

[a] Ann. Rept. Geol. Survey Canada, vol. 10, pt. 1, for 1897, pp. 302.

granite near Onaping, on the Canadian Pacific Railway northwest of Sudbury. At the contact is conglomerate or breccia or pyroclastic rock containing fragments of granite, greenstone, slate, and quartzite, each of one or more varieties. The fragments are both angular and rounded, and sedimentary material appears in the matrix. Resting against the granite, and apparently under the conglomerate or breccia, is a thin film of quartzite similar to that appearing as pebbles in the conglomerate.

At Wahnapitae they examined the contact of the Laurentian granite with the quartzite of Bell's Huronian series, and found it to be a case of intricate intrusion and granitization.

About half a mile east of Sudbury they found a breccia or conglomerate similar in every way to that seen at Onaping, resting on the eroded edges of Huronian quartzite and containing fragments of it. There is here present also a peculiar tuffaceous quartzite, different from the breccia, which probably is of the same age as the older quartzite. It is believed that the later tuff of this locality, together with Bell's Cambrian, is younger than both of the clastic Huronian series of the north shore of Lake Huron.

The nickel-bearing norite probably belongs with the upper series in age. In the vicinity of Copper Cliff and the Murray mines the succession seems to be: (1) Quartzite, including both normal and tuffaceous phases; (2) schistose diorite, which is well banded and locally granitized; (3) gray granite; (4) norite; (5) red granite.

In a reconnaissance from the train from Sudbury west to Cutler, 77 miles, quartzite (Huronian of Bell) was seen as the predominating rock along the railway. Beyond Cutler diorite, apparently intrusive into quartzite and in turn cut by red granite, appears in quantity, and continues nearly to Algoma. At Algoma and westward to Blind River, a distance of 7 miles, the quartzite was again seen. From Blind River the granite is predominant and dioritic schist is the subordinate rock until Dayton is reached, beyond which to Thessalon the predominating rock is the dioritic schist.

Van Hise and Leith,[47] in 1902, make a somewhat detailed study of the Huronian area eastward from Sault Ste. Marie to Thessalon. Between the "Soo" and Garden River the "Lower slate conglomerate" of Murray was found to contain granite, greenstone, and green schist fragments, the granite fragments being similar to granite in solid ledges a few paces to the north. A short distance to the east what was taken to be the same conglomerate was found both north and south of the lower limestone in such a position as to suggest that the structure is anticlinal and that the conglomerates both north and south are later than and unconformably above the limestone. If this be so, the conglomerate mapped as lower slate conglomerate by Logan is really upper slate conglomerate. To the east, at the old limestone quarry north of Garden River, the unconformity between the upper slate conglomerate and the limestone was again examined. At Echo Lake, where Logan had mapped a southward-dipping monoclinal succession of lower slate conglomerate, limestone, and upper slate conglomerate, the succession was found to be: Quartzite, constituting the thickest formation above the lake, grading upward through graywacke into thin conglomerate not more than 30 feet thick, containing granite and green schist fragments, this in turn into limestone not more than 50 feet thick, and this overlain by the upper slate conglomerate in considerable thickness. This upper slate conglomerate bears many well-rounded fragments of the limestone of varying sizes, showing a marked unconformity between the two formations. The limestone, instead of occurring in a single east-west band with southerly dip, is in a series of synclinal patches, and the conglomerate both to the north and to the south is the thin lower slate conglomerate brought up by the synclinal structure.

From Echo Lake southeastward to Thessalon the mapping of Logan and Murray was found to be substantially correct. Certain features in the vicinity of the Bruce mines suggest that there may be an unconformity above the slate conglomerate, but these are not decisive.

The estimate of the thickness of the Huronian, 18,000 feet, by Logan and Murray is far too large, the true thickness probably not exceeding 12,000 feet.

The contact of Logan's gray quartzite and granite to the east of Thessalon was again examined and the conclusion of previous years, that the conglomerate, resting unconformably upon the granite, presumably represents the base of the Huronian series, was confirmed. The possibility having suggested itself that this conglomerate might represent the base of an upper series of the district, the area to the northwest was studied and the conclusion was reached that the conglomerate is at the base of the Huronian of the district, as mapped by Logan and Murray.

MILLER,[48] in 1903, gives a résumé of the occurrence of iron ore in northern Ontario and incidentally discusses their geological relations.

COLEMAN,[49] in 1903, describes and maps the nickel deposits near Sudbury, Ontario, and incidentally discusses the geology of the region. The probable succession and age of the rocks of the district are as follows, in ascending order:

Keweenawan (?)	Dikes of diabase. Younger granite. Nickel-bearing eruptive; norite; micropegmatite; granite.

Animikie (?) or Upper Huronian (?)—Oval area of tuffs, sandstones, and slates, overlying the preceding.

Laurentian—Granitoid gneiss.

Upper Huronian	Green schists and greenstones. Arkoses, quartzites, and graywackes.

It can hardly be said that the precise age of any of these groups of rocks is known, though they probably range from the base of the Upper Huronian to the Keweenawan, including the Laurentian as later than the Upper Huronian. No rocks undoubtedly of Lower Huronian age are known from the nickel district proper, though the ranges of banded silica and magnetite extending through Hutton and Wisner townships to the north of the nickel area evidently belong to the Lower Huronian.[a] The latter rocks occur, so far as known, entirely inclosed in granites and gneisses, generally considered Laurentian, and have not been found in direct connection with the rocks here described.

The fact has been brought out that all of the nickel deposits are either on the basic edge of a great eruptive band, which at the opposite edge becomes a quartz syenite or granite, or on dikelike offshoots, often, however, interrupted by other rocks projecting from the southeastern basic edge of the great gabbro band. This band has been found to outcrop in a great oval, the north and south sides of which have been known respectively as the North and South nickel ranges. The structure is synclinal and the center is occupied by Animikie or Upper Huronian rocks.

There are two different types of deposits represented in the mines of the district—those along the southeastern margin of the main range, often crowded into baylike indentations of the adjoining rock, and those strung out along the narrow offshoots from the main range, as Peters suggests, "like sausages on a string, but with a long piece of string between the sausages."[b] Among the former class are the Creighton, Gertrude, Elsie, Murray, and Blezard mines; among the latter, the Copper Cliff, Evans, Frood and Stobie, and the Victoria and Worthington mines. Perhaps a third variety should be distinguished for the Vermilion mine, which contains rich nickel and copper ores, but has no visible association with a band of gabbro, having, however, been formed probably by hot circulating fluids proceeding from such a band.

The final impression left is that the marginal type of deposit is in the main of plutonic origin, aqueous work having been relatively unimportant; that in the offset type plutonic is generally more important than aqueous action, though one example, the Worthington, suggests more complete rearrangement of the materials by circulating water, thus forming a transition to ordinary vein deposits wholly due to water action, as at the Vermilion mine.

LEITH,[50] in 1903, describes the Moose Mountain iron range in the township of Hutton and district of Nipissing. Iron formation consisting of magnetite, of banded magnetite and quartz, and of mag-

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[a] Rept. Bur. Mines Ontario, 1901, p. 186.
[b] Min. Res. Ontario, p. 104.

netite associated with amphibole and epidote occurs in bands and lenses in a complex of basic igneous rocks characterized by uniform abundance of amphiboles. Some of the greenstones are basal and some are intrusive into the iron-bearing bands. Intrusive into the greenstone and probably into the iron formation are granite masses. Closely associated with the iron formation, but with relations unknown, is a pyritiferous graywacke. The ores and associated rock as a whole are in general similar lithologically to the Vermilion iron-bearing district of Minnesota, although showing many points of difference.

Bolton,[51] in 1903, reports on a geological reconnaissance from Round Lake north to the Abitibi River in the district of Nipissing. Laurentian granite was seen near both the southeastern and the southwestern corners of Eby. Elsewhere Huronian rocks are exposed. Of these there is a considerable variety, many of which are of fragmental origin. The following types were seen: Diorite, diabase, brecciated conglomerate, slate, graywacke, hornblende schist, etc. As the rock outcrops of the district explored are as a rule separated by areas of sand or swampy or clayey soil, the relations of the different types could seldom be worked out.

Graton,[52] in 1903, reports on a geological reconnaissance along Mississaga River, and east and west along Niven's base line, in the district of Algoma. Laurentian granites occupy all of the area north of Township 188, where was found a greenish slate conglomerate belonging to the Huronian.

Van Hise, Leith,[53] and assistants, in 1903, by an examination of the area westward from Lake Temagami to the Onaping River, find that the basement rocks of the region are greenstones and green schists, with associated iron formation, similar in all respects to the Keewatin (Archean) greenstones, green schists, and iron formation of the Vermilion and Marquette iron-bearing districts of Minnesota and Michigan. Intrusive into these rocks are granites of two or more ages, a considerable part of which are Laurentian. Unconformably overlying the greenstones, green schists, and iron formation, and at least part of the granites, are two or more unconformable series of Huronian sediments, including conglomerate, quartzite, slate, and limestone, for the most part not greatly metamorphosed or folded. Unconformable contacts with the Keewatin were noted between the sediments and basal rocks on Emerald Lake and west of Morin Lake, north of the township of Kitchener, and contacts of the Huronian and Laurentian were noted on Rabbit Lake, west of Morin Lake, and on Onaping Lake. Contacts between the upper and lower sedimentary Huronian series were found on Temagami and Emerald lakes and at several localities west of Hutton. The general outlines of the igneous and sedimentary series were determined for an area of 800 square miles, but no attempt was made to separate the different sedimentary series.

INGALL,[54] in 1903, gives a brief preliminary account of a resurvey of the Bruce Mines district, in the Original Huronian district.

BARLOW,[55] in 1904, discusses the geology of the Temagami district in eastern Ontario. Lower and Upper Huronian rocks intruded by granite and gabbro are present. The Lower Huronian consists of greenstone, green schist, sericite schists, slates, dolomite, and iron formation, with intrusive granites. The Upper Huronian consists of breccia or slate conglomerate, slate, and quartzite. The iron ranges, with accompanying green schists, slates, dolomites, and schistose eruptives, and intruded by granites, belong to a series which had been intensely folded, metamorphosed, and considerably eroded before the deposition of the overlying conglomerate hitherto described as the basal member of the Huronian system in this region. The larger fragments in the conglomerate are principally pebbles of granite and greenstone derived from the degradation of this underlying series. The immediate junction between this older series and the unconformably overlying conglomerate is well seen at a point on the south shore of the northeast arm about 15 chains west of the portage into Cariboo Lake. The occurrence of the ores is believed to be similar to that of the Vermilion district of Minnesota, and their origin is believed to be similar to that described by Van Hise for the Lake Superior ores.

ADAMS, BELL, LANE, MILLER, and VAN HISE,[56] in 1904, visited various points in the Original Huronian district of the north shore of Lake Huron. At the old limestone quarry at Garden River it was found, further, that the conglomerate to the north of the limestone, mapped as lower slate conglomerate by Logan and Murray, contains fragments of limestone and is unconformably above it, thus being the same in age as the conglomerate south of the limestone—that is, upper slate conglomerate. The limestone thus forms an anticline. This observation tends to confirm the conclusions reached two years previous by Van Hise and Leith, that the limestone at Root River to the west is anticlinal and that the conglomerate both to the north and south of it, as well as conglomerate farther to the west, resting against the granite, is the upper slate conglomerate, unconformably above the limestone.

It was concluded that there is a structural break in the Huronian. The upper series includes, in descending order: (1) White quartzite, chert, and limestone; (2) yellow chert and limestone; (3) white quartzite; (4) red jasper conglomerate; (5) red quartzite; (6) upper slate conglomerate. The lower series includes: (1) Limestone; (2) lower slate conglomerate; (3) white quartzite; (4) gray quartzite. It was recommended that these series be called the Upper and Lower Huronian series.

The "green chloritic slate" mapped by Logan and Murray near Thessalon was found to consist of ellipsoidal greenstones, amygdaloids, agglomerates, and massive greenstones, collectively referred to as the Thessalon series. No undoubted sediments were observed. The granite and gneiss, mapped by Logan as Laurentian, are intrusive into the Thessalon series. The conglomerate and quartzite at the base of Logan's Huronian series are found to rest unconformably upon the granite east of Thessalon, and probably also upon the Thessalon series, thus confirming the like conclusions of Irving, Pumpelly, and Van Hise based upon earlier observations. Accordingly the Thessalon series should be excluded from the Huronian and assigned to the Keewatin division of the Basement Complex.

Coleman,[57] in 1904, describes and maps the northern nickel range of the Sudbury district of Ontario. It constitutes the northern upturned edge of a syncline of eruptive rocks resting on Laurentian granites and gneisses and including within it a little-disturbed basin of Cambrian or Upper Huronian sediments and tuffs. The contacts with the rocks above and below are eruptive. The eruptive grades from acidic in its inner or upper margin to basic in its outer or lower margin. The nickel is concentrated in its basic edge.

Barlow,[58] in 1904, describes and maps the geology of the Sudbury nickel and copper district of Ontario. He makes the succession as follows:

1. Lower Huronian. No rocks of this age are at present known in the nickel-bearing area, but this period is represented in part by the banded siliceous magnetites and associated rocks of the townships of Hutton and Wissner.

2. Upper Huronian. (*a*) Diorites, hornblende porphyrites, and green schists. (*b*) Conglomerates, graywackes, and quartzites. (*c*) Norite and diorite (Worthington mine belt and areas southeast of Evans mine and east of Sudbury).

3. Laurentian. Granite and diorite gneiss near Wanapitei station.

4. Upper Huronian? Tuffs, feldspathic sandstones, and slates, classified provisionally on previous geological maps as of Cambrian age.

5. Post-Huronian. (*a*) Granites. (*b*) Nickel-bearing eruptive of the main belt (quartz-hypersthene gabbro or norite, diorite, with their peculiar differentiation product, micropegmatite). (*c*) Dikes of olivine diabase.

On the maps the rocks are lithologically separated and grouped as Archean.

The nickel is confined to the norite and its altered varieties. Closely associated with this is a rock of granitic composition and prevailing gneissoid texture, which can not be sharply separated from the basic eruptive, although the change is usually sharp enough to enable a boundary to be placed between them. Together they probably constitute the exposed edges of a laccolith folded into a basin shape and containing in its depressed interior the Upper Huronian (?), as held by Coleman. The nickel is mainly in the form of a nickel-iron sulphide, pentlandite, associated with pyrrhotite and chalcopyrite. It is believed to be essentially an original constituent of the norite magma, although locally segregated through the agency of hot gaseous and aqueous solutions accompanying later stages of the norite eruption.

Kay,[59] in 1904, describes the rocks seen on a trip from Mattagami to Nighthawk and the area west of Lake Abitibi. No attempt is made to describe their stratigraphy and structure.

Miller,[60] in 1904 and 1905, maps and describes the silver-cobalt area near Haileybury, on the northwest shore of Lake Temiskaming, Ontario. The succession is as follows, from the base up:

1. Laurentian. Lorrain granite. This granite is intrusive into the Keewatin, but not into the Lower Huronian.

   Igneous contact.

2. Keewatin. This series is an igneous complex, consisting of greenstones, quartz porphyries, and other rocks. It has been more or less folded and disturbed.

   Great unconformity.

3. Lower Huronian. The Cobalt series, consisting of conglomerate, breccia, quartzites, and graywacke slate. Outcrops of the coarser varieties of the rocks are confined almost entirely to the area east of a line which runs from the east side of Mud Lake northeastward to about lot 6 in the fifth concession of Bucke. West and southwest of this line there is much reddish banded slate and quartzose graywacke. The cobalt-nickel-arsenic-silver veins occur largely in this series.

   Unconformity.

4. Middle Huronian. Lorrain arkose, quartzite, and conglomerate.
5. Diabase and gabbro. These igneous rocks cut through all the other pre-Cambrian series in the field. Their exact age is not known. They may belong either to Animikie or Keweenawan time. The ores of the district may have been deposited from highly heated mineral-laden waters associated with the eruption.

   Great unconformity.

6. Niagara. Limestone with a small amount of sandstone and conglomerate at its base.

Ingall and Denis,[61] in 1905, report on the geology of the country around the Bruce mines. Corrections are made in the areal distribution of the part of Logan and Murray's Original Huronian succession found in this area.

Parks,[62] in 1905, reports on the geology of a district from Lake Temiskaming northward, including a part of the Cobalt district. The description of the Cobalt district is similar to that given by Miller, though the classification and nomenclature used by Miller are not followed. In the country to the north rocks of a similar nature extend in a somewhat narrow band from the outlet of Windigo Lake, in the township of Marter, to the Height of Land north of Opazatica or Long Lake. There is evidence that its trend there becomes more easterly and that it follows the great Height of Land ridge farther into Quebec. The southeasterly limit of the belt is approximately a line from the south end of Fish Lake, on the international boundary, to a little beyond the northeast angle of the township of Ingram.

Young,[63] in 1905, reports on the area between Rabbit and Temagami lakes. The geological succession is similar to that in the Northeast Arm of Lake Temagami. The oldest series of rocks consists chiefly of schists, which in one area are mainly chloritic and sericitic, while in a second area hornblende and mica schists predominate. These schists are penetrated by masses of granite of at least two varieties, one of which is also cut by a body of syenite. The schists and intrusive masses of granite and syenite are in places unconformably overlain by a heavy conglomerate, which almost invariably grades up into a slate, and the latter in one instance is conformably overlain by a bed of quartzite. The beds of slate and conglomerate as a whole occur horizontally and are frequently capped by sills of diabase. The diabase is also found resting on the schists and granites. Diabase dikes intersect the schists, the granites, and the overlying conglomerate and slate formation; their relation to the sheets of diabase was not observed.

Coleman,[64] in 1905, describes and maps the geology of the Sudbury nickel basin of Ontario. His sedimentary succession is as follows:

Later	Upper Huronian–Animikie	Chelmsford sandstone. Onwatin slate. Onaping tuff. Trout Lake conglomerate.
Archean	Middle Huronian	Ramsay Lake conglomerate.
	Lower Huronian	Quartzite. Graywacke and slate.

Intrusive into the rocks of the Lower and Middle Huronian are acidic and basic eruptives consisting of altered diabases, porphyrites, norite, gabbro, and granite. Also intrusive are other granites and gneisses assigned to the Laurentian. Between the Animikie and the lower sediments there is intruded a laccolithic mass, the folding of which is such that it constitutes a boat-shaped basin carrying the Animikie within it. Its average thickness is 1¼ miles. The outer edge of this eruptive is basic and carries the nickel deposits. Toward the inner edge there is a gradation into acidic rocks. The ores are believed to be the result of magmatic separation, modified by later solution and redeposition.

Miller,[65] in 1905, makes a report upon the Boston Township iron range of northeastern Ontario. The range consists of iron-formation bands and lenses associated with Keewatin greenstones and green schists, as in the Vermilion district of Minnesota. Following the nomenclature of the joint geological committee, he finds the succession from the base up: Laurentian granites, Keewatin greenstones, Lower Huronian sediments, trap dikes. The iron formation consists of banded jasper and siliceous material. Its length is approximately 6 or 8 miles and its width 90 to 300 feet. Intrusions have cut it to a considerable extent. Miller's report adds to the literature the description of another area in Ontario in which Lake Superior succession and conditions of iron formation are repeated.

KERR,[66] in 1906, reports on the explorations of the Mattagami Valley, in Ontario, northeast of Lake Huron. Most of the rock exposures are in the southern part of the area, south of Niven's second base line. The Huronian belt extends from the foot of Kenogamisse northward as far as Loon portage on the Mattagami, where the first Laurentian rocks were seen. The contact between the two formations was also located south of this, on Muskego River. The Laurentian stretches from here to Poplar Rapids, as far north as his exploration extended.

BROCK,[67] in 1907, maps and describes the geology of the Larder Lake district, in eastern Ontario. West and north of the lake is a complex consisting of phyllites, schists, cherts, ferruginous dolomites, and greenstones, cut by igneous rocks. These rocks as a rule are lying on edge and are characterized by the disturbances and metamorphism to which they have been subjected. Cutting them at various points about the lake are pegmatite and quartz porphyry dikes, evidently connected with a granite intrusion. From the number of granite bowlders scattered over the surface it is evident that not very far away the granite is exposed. While later than the rocks of the complex, the rocks of the granite family are undoubtedly older than the sedimentary rocks mentioned below as overlying the old complex, since these sedimentaries contain fragments of the granites.

Lying unconformably upon the preceding complex is a series of sedimentary rocks consisting of slates, quartzites, and conglomerates. These are for the most part undisturbed, with gentle dips, except in the immediate vicinity of a later igneous intrusion, where they may show considerable local metamorphism. In such cases differentiation from the earlier complex may be somewhat difficult, but the undisturbed condition of these rocks affords the readiest criterion for their recognition. This series is exposed on most of the islands of the main body of the lake, on the north shore near the narrows, and on the east shore of the lake.

Later than and intrusive in the rocks above mentioned is an igneous rock which in places presents a gabbro facies and in other places a diabase, and also a series of usually small, basic, mica dikes.

The rocks of the basal complex correspond perfectly, in position, in lithological character, and in their disturbed and metamorphosed condition, to the oldest formation in the Lake Superior and Lake Huron districts, which the international committee on geological nomenclature recommended should be called Keewatin. The rocks of the granite family correspond to the Laurentian as defined by this committee, and the sedimentary series to the Lower Huronian. As no rocks newer than the diabase or gabbro were seen, it can be classified only as post-Lower Huronian.

Above the solid formations are glacial and postglacial deposits of clay, sand, and gravel. There are, then, in descending order, the following formations:

Postglacial	Clays, sands, gravels.
Glacial	Bowlder clay.
Great unconformity.	
Post-Lower Huronian	Diabase, gabbro, mica lamprophyres.
Igneous unconformity.	
Lower Huronian	Conglomerate, quartzite, slate.
Unconformity.	
Laurentian	Granite, pegmatite, porphyry.
Igneous unconformity.	
Keewatin	Greenstone, lime, silicate rocks, schists, dolomites, cherts, etc.

Coleman,[68] in 1908, concludes that lower Huronian conglomerates of the Cobalt district show convincing evidence of glacial action, and that the occurrence of similar rocks at various localities westward for 200 miles in Ontario points to a general Huronian ice age.

Miller,[69] in 1908, in a third report on the Cobalt district, discusses certain possible fragmental sediments and jasper-magnetite bands of undoubted sedimentary origin. The writer believes that these sedimentary bands should be classed with the Grenville series, which is found in much greater volume in southeastern Ontario. He would place the Grenville sedimentary series between the Keewatin and lower Huronian in age.

Knight,[70] in 1908, discusses the geology of part of Montreal River and the Temagami Forest Reserve, Ontario. The succession is as follows:

Glacial and postglacial	Bowlder clay, sands, gravels, clays.
Great unconformity.	
Huronian or Keweenawan (?)	Diabase.
Igneous contact.	
Huronian	Quartzite, arkose, conglomerate, and slate.
Great unconformity.	
Laurentian	Granite, syenite, and gneiss intrusive into Keewatin but not into Huronian.
Igneous contact.	
Keewatin	The series is an igneous complex, consisting generally of highly metamorphosed basic igneous rocks.

This succession does not differ essentially from that in the Cobalt district, except that there is an apparent lack of iron formation in the Keewatin.

Knight,[71] in 1908, discusses the geology of an area south of the township of Lorrain and finds essentially the same succession and structure as in the Cobalt district.

Hore,[72] in 1908, finds the succession and structure of the townships of Casey and Harris at the north end of Lake Temiskaming to be the same as described by Miller for the Cobalt district.

Similar results are reached from the study of an area south of Lake Wendigo.

DeLury,[73] in 1908, discusses the geology of an area west of Bay Lake, on Montreal River. He finds Huronian sediments and intrusives similar to those in the Cobalt district, but not Keewatin rocks.

SUMMARY OF PRESENT KNOWLEDGE.

NORTH SHORE OF LAKE HURON.

Logan and Murray's work.—Bigsby's Transition series (1821) is that to which the term "Huronian" was later applied by Logan and Murray, and hence his description of this series is the earliest. Logan and Murray, beginning their studies of the north shore of Lake Huron in the forties, first applied the term "Huronian" to the clastic rocks of the district in 1857. In their general report, 1863, they applied the term "Huronian" to nearly all of the pre-Animikie rocks (except granites and gneisses of the "Laurentian") of the Lake Superior and Lake Huron regions, and showed the distribution of the "Huronian" on a general map of the eastern half of Canada and adjacent portions of the United States. But the north shore of Lake Huron, which gives the series its name, is the original Huronian district. Discussion of correlation and nomenclature of the Huronian series in general correctly refers to this district as the type.

The pre-Cambrian succession in the original Huronian district, as given by Logan and Murray, is as follows:

Huronian	White quartzite, chert, and limestone.
	Yellow chert and limestone.
	White quartzite.
	Red jasper conglomerate.
	Red quartzite.
	Upper slate conglomerate.
	Limestone.
	Lower slate conglomerate.
	Green chlorite slate.
	White quartzite.
	Gray quartzite.
Laurentian	Upper Laurentian (wanting).
	Lower Laurentian, granites, and gneisses.
Intrusive	Greenstone.
	Syenite.

Great indisputable results were reached by the early Canadian geologists, Logan and Murray. This district north of Lake Huron was the first in which it was shown that an unmistakable detrital and little metamorphosed series of rocks rests unconformably under the upper Cambrian. Also it was shown that this series is of such a character that the ordinary stratigraphic methods apply, and Logan and Murray were able to subdivide it into formations upon a lithological basis in the same manner as is done in fossiliferous series. This is so evident that it would not be emphasized if it had not been denied. Far more to the credit of Logan and Murray is the recognition of the character of the amygdaloids and the interbedded greenstones. No extreme metamorphic theory was applied to them, and they were distinctly regarded as an exception to the ordinary stratigraphic laws and were separated both in descriptions and in mapping. This is the more creditable because for many years afterward similar rocks were supposed by many other writers to be parts of the stratified successions in a completely metamorphosed condition that had caused them to become crystalline. Finally it was recognized that this Huronian series rests unconformably upon an older gneissic and granitic crystalline series, which has yielded abundant fragments to the overlying rocks.

The only rocks in the original Huronian area which Logan correlated with those of the original Laurentian area are the unconformably underlying granitic and gneissic series. These were called "Lower Laurentian," the idea being evidently to correlate them with the lower noncalcareous division of the original Laurentian. This correlation was plainly made on the ground of lithological likeness. That the Huronian is more recent than the "Upper Laurentian" was stated only as a belief. This belief appears to have been based upon the "nonmetamorphic" character of the Huronian as compared with the "Upper Laurentian." It is also possible that the fact that there is a structural break on the north shore of Lake Huron between the Huronian and the gneissic series, whereas no such break was found between the upper and lower divisions of the original Laurentian, had an influence in leading to this conclusion.

As to the relations of the "Huronian" and "Laurentian" north of Lake Huron, Murray, in 1857, made the distinction to rest upon age and upon lithological characteristics, the "Laurentian" being older and more completely crystalline than the "Huronian." While the "Huronian" and "Laurentian" of Logan and Murray are not described at any definite locality as having unconformable relations, Logan states that the "Huronian" is a stratified series and reposes discordantly upon the "Laurentian system," and in 1858 he again clearly indicates the same thing by the statement that in the slate conglomerates are bowlders and pebbles derived from the subjacent gneiss and that the lower formation was consequently converted into gneiss and probably greatly disturbed before the upper series was laid down. In 1865 Logan further says that the Huronian unconformably overlies the "Lower Laurentian," and is believed, although not found in contact with it, to be more recent than the "Upper Laurentian." These statements are emphasized by his sections published in 1863, which represent the Huronian as resting unconformably upon the "Laurentian."

Developments subsequent to Logan and Murray's work.—The net result of all subsequent work has been to confirm the essential correctness of Logan and Murray's succession and structure. In view of the early date of their work and the great difficulties of travel in this district their results are marvelously accurate. Additional important discoveries as to the structure and relations of the rocks have naturally been made. Principal among these are the discovery of an unconformity within the Huronian clastic series and an unconformity between the clastic series and a greenstone series below, mapped by Logan and Murray as green chloritic slate and regarded by them as Huronian, and the determination of the detailed structure and thickness of the different series. In the light of the most recent work, the succession is, regardless of names and correlation, as follows, in descending order:

1. White quartzite, chert, and limestone.
Yellow cherty limestone.
2. White quartzite.
Red jasper conglomerate.
Red quartzite.
3. Upper slate conglomerate.

    Unconformity.

4. Limestone.
5. Lower slate conglomerate.
6. White quartzite.
Gray quartzite.

    Unconformity.

7. Ellipsoidal greenstone and green schist intruded by granite gneiss.

This succession shows fewer units than that of Logan and Murray, two or three of their units having been grouped into single formations in the present table. Logan and Murray's units were in these cases smaller than the formation, which is the smallest unit used by the United States geologists in mapping the Lake Superior country.

Unconformity within the Huronian.—That an unconformity existed within the Huronian series was first maintained by Alexander Winchell, in 1891; he concluded, mainly from discordance of bedding, both within and without the original Huronian district, that there is an unconformity between the upper slate conglomerate and the lower slate conglomerate, but he placed the limestone with the upper group. In 1892 Pumpelly and Van Hise visited the area and found contacts which proved the existence of an unconformity between the two conglomerates. But the upper slate conglomerate rests upon and carries fragments of the limestone, where this is not entirely removed by erosion, thus showing that this formation belongs to the lower rather than the upper group. In 1902 the district was again visited by Van Hise and Leith and some six weeks spent in attempting to ascertain the importance of this unconformity. The results of this work, summarized on a preceding page, indicate that the unconformity is one of considerable magnitude, representing a time interval long enough to allow of the truncation of the underlying group. This unconformity was for the most part not recognized by the Canadian geologists until the time of the meeting of the international geological committee in this district in 1904.

Thickness of the Huronian sediments.—The structural work of Van Hise and Leith in 1902 showed that the thickness of the Huronian has probably been greatly overestimated.

Relations of Huronian sediments to underlying rocks.—Since Logan and Murray's time the "Laurentian" granite has been until recently regarded by Canadian geologists not only as intrusive into what they call the "Lower Huronian," but by Barlow as intrusive even into the "Upper Huronian." The first to describe an actual contact between the underlying gneissic series and the overlying Huronian sediments was Irving, who, in 1887, clearly showed that such an unconformity occurs. The observations of Pumpelly and Van Hise reinforced this conclusion, and show that between the lowest clastic member of the Huronian and the Laurentian complex there is a very great discordance. This was further confirmed in 1902 by Van Hise and Leith and in 1904 by the joint committee. The committee also observed that the same formation which rests unconformably upon granite also rests unconformably upon the Thessalon group of Keewatin rocks (Logan's chloritic slates), and that the Thessalon Keewatin is intruded by the Laurentian granite. It being admitted that the Thessalon contact of Huronian with Laurentian and Keewatin rocks represents a true erosional unconformity, the question may still be asked whether this conglomerate is at the base of the lower Huronian. It is difficult to show this beyond doubt, but the evidence that such is the fact is very strong.

In the Sudbury district to the northeast granites abundantly intrude the Huronian series.

SUDBURY DISTRICT.

The succession is as follows, from the base up:

1. Keewatin greenstones, green schists, and iron formation. These do not occur in the Sudbury district proper, but are found bordering it immediately to the north. They are correlated with the Thessalon group of the original Huronian area. These appear on the Canadian maps as "Lower Huronian."

2. Lower Huronian resting unconformably upon the Keewatin rocks. Conglomerates, graywackes, and quartzites, associated with diorites, hornblende porphyrites, norites, and green schists. In the Wahnapitae area, immediately east, they contain limestones. They might perhaps be correlated with either the middle or the lower Huronian of the original Huronian district proper, but because of the presence of limestone they are correlated with the lower Huronian. On the Canadian maps they appear as "Upper Huronian."

3. Granite, diorite, gneiss, gabbro, and porphyrite, intrusive into lower Huronian. Part of the granite and gneiss is referred to the Laurentian by Bell, Barlow, and Coleman. All of the preceding sedimentary rocks and part of the igneous rocks are folded, metamorphosed, and eroded.

4. Upper Huronian resting unconformably upon underlying rocks, tuffs, feldspathic sandstones, and slates. Correlated with the Animikie group of Lake Superior. Mapped by Bell as "Cambrian," by Coleman as "Animikie or Upper Huronian," and by Barlow as doubtful "Upper Huronian." This group constitutes a boat-shaped basin called the Sudbury basin.

5. Granites, nickel-bearing eruptives (quartz-hypersthene gabbro or norite, diorite, micropegmatite), and dikes of olivine diabase. In part later than the upper Huronian and perhaps of Keweenawan age; in part apparently interbedded with upper Huronian. A part of these lie beneath the upper Huronian and outcrop around the edge of the upper Huronian basin. The norite at the base is the nickel-bearing eruptive. According to Coleman this norite grades upward—that is, toward the inner edge of the eruptive belt—into an acidic rock. According to Barlow these rocks are merely intrusive into the basic rocks.

LAKES TEMISCAMING AND TEMAGAMI AND WESTWARD TO LAKE ONAPING.

Throughout this area may be observed rocks similar to those on the north shore of Lake Huron and the Michipicoten district. At the base are Keewatin greenstones, green schists, and iron formation, cut by Laurentian granites and gneisses. Lying unconformably upon them are, in different areas, one, two, or possibly three unconformable groups, cut by basic and acidic intrusives, assigned to the Huronian.

This succession and nomenclature appear on Miller's map of the silver-cobalt area near Haileybury, on Lake Temiscaming, and on Brock's map of the Larder Lake district to the north. In the Cobalt district the Keewatin is identical in every respect to that of the Lake Superior country, and particularly to that of the Vermilion district, Minnesota, even to the existence of ellipsoidal structures in the basalt and intrusion by peculiar "white-eyed" quartz porphyries. Laurentian granites and gneisses intrude the Keewatin. Resting upon both, with marked unconformity, are two Huronian groups of slates and quartzites, correlated with the middle and lower Huronian. The upper group is much less metamorphosed than the lower. The correlation with the middle and lower Huronian rather than with the upper and middle or the upper and lower is tentative and not supported by structural evidence. Intrusive into all the groups are gabbro and diorite, provisionally correlated with the Keweenawan.

Miller believes that a similar succession exists somewhat widely beyond the limits of his map in all directions. Van Hise and Leith have mapped about a thousand square miles in the area extending from Lake Temagami westward to Lake Onaping and in the area northward from Biscotasing, and find similar groups with similar relations throughout these areas, but whether two or three Huronian groups are present is not yet known.

Brock has found the same groups and relations in the Larder Lake district of the Height of Land north of Lake Temiscaming.

The relations of the granites and gneisses to the sedimentary rocks of this region have been disputed. The Temagami area has been cited by Barlow as affording strong evidence of the intrusion of the Laurentian granites into the Huronian sediments. An examination of the contact at two places by Van Hise and Leith in 1903 showed conclusively that the Huronian series rests, with normal erosion unconformity with clearly defined conglomerates, against the Laurentian granites. These conglomerates had previously been referred to as breccias. Miller's map of the Cobalt area to the north shows similar facts. The existence of conglomerates and the fact that granite is unconformably below the Huronian series are now admitted by Barlow, but he still is inclined to hold that much the larger part of the granite is intrusive into the Huronian series. We are not prepared to state what part of the granite is unconformably below the Huronian series, but our mapping in this area, extending over 1,000 square miles, has shown the presence of a much larger amount of pre-Huronian than Huronian or post-Huronian granite.

GENERAL CORRELATION AND NOMENCLATURE OF HURONIAN SERIES.

The two sedimentary groups of the original Huronian district—that is, the portion of the north shore of Lake Huron mapped in detail by Logan and Murray—have been called the upper and lower Huronian series by Irving, Van Hise, Pumpelly, and their associates, and the upper of the two groups has been correlated with the Animikie group. On the other hand, the Canadian geologists have uniformly held that the Animikie is younger than the original Huronian series and that, for this reason, it should not be called Huronian. The retention of the Animikie in the Huronian, notwithstanding the recognition of the fact that the Animikie is younger than the series of the original Huronian district proper, is believed to be warranted by the following facts: Logan and Murray in 1863 applied the term "Huronian" to what they believed to be essentially a sedimentary series on the north shore of Lake Huron. Where it was mapped in detail (1863) by Logan and Murray it has been subsequently found to include two sedimentary groups resting on an igneous basement. But at the same time they published a general map showing the distribution of the "Huronian" for the region as a whole, and on that map both the Animikie of the north shore of Lake Superior and the sediments to the northwest of Sudbury, later mapped by Bell as "Cambrian," are included under the "Huronian." While both are now recognized as overlying the Huronian series of the original Huronian district proper, it is believed that both are entitled to the term Huronian. A threefold division takes the place of a twofold division of this series. Logan and Murray did not subdivide the series at all, and hence the twofold division previously held for the region as a whole does not have the authority of their mapping any more than the threefold division now proposed.

The joint geological committee in 1904 adopted the threefold division of the Huronian, and is thus in essential accord with the above conclusions. The committee did not cover all of the district.

There are, then, two unconformable sedimentary groups in the original Huronian district proper. Logan's general map of the Huronian included the Sudbury region to the northeast, where there is a sedimentary group (Bell's Cambrian, Barlow's and Coleman's Upper Huronian) which is younger than either of the two groups of the original Huronian district. The Huronian series of the general region north of Lake Huron is therefore divided into three groups—upper Huronian, lower Huronian, and middle Huronian. The upper Huronian is similar in lack of folding and metamorphism and in part in lithology to the Animikie group of the north shore of Lake Superior and is correlated with that group. The middle and lower Huronian north of Lake Huron are similar in lithology, structure, and metamorphism to the middle and lower Huronian underlying what is here regarded as the equivalent of the Animikie group in the Marquette district of Michigan, and are accordingly correlated with them. On the same basis the lower Huronian may be correlated with the cherty limestone and quartzite of the lower Huronian of the Gogebic district and with the Randville dolomite and Sturgeon quartzite of the Crystal Falls and Menominee districts. In the Minnesota districts there is nothing in the lithological character of the sedimentary group beneath the Animikie and above the Archean to indicate whether it should be correlated with the lower Huronian or with the middle Huronian or partly with each. The basis for their correlation with the Huronian is simply their occurrence in a similar general succession between the Archean and the Animikie.

The Huronian series rests unconformably on the Archean system, composed of the Keewatin and Laurentian series, which are correlated with the Keewatin and Laurentian of the Lake Superior region. This unconformity is the same as that designated "inter-Huronian" by certain of the Canadian geologists who have applied the term "Lower Huronian" to the Keewatin rocks.

The succession and nomenclature of Logan and Murray, later Canadian geologists, and United States geologists are summarized in the following table:

Pre-Cambrian succession in area north and northeast of Lake Huron, as given by Canadian and United States geologists.

	Usage followed in present report.	Logan and Murray.	Later Canadian geologists.	United States geologists, early usage.
Algonkian.	Huronian series: Upper Huronian, slates, sandstones, conglomerates, and volcanic breccias of basin north of Sudbury.	Huronian.	Bell, I., Cambrian. Coleman, Upper Huronian (?).	Huronian.
Algonkian.	Unconformity.	Huronian. White quartzite, chert, and limestone. Yellow chert and limestone. White quartzite. Red jasper conglomerate. Red quartzite. Upper slate conglomerate. Limestone. Lower slate conglomerate. White quartzite. Green chlorite slate. Gray quartzite.	Unconformity.	Upper Huronian.
Algonkian.	Middle Huronian, white quartzite, chert, and limestone, yellow cherty limestone, white quartzite, red jasper conglomerate, red quartzite, and upper slate conglomerate.		Upper Huronian, except green chloritic slate, which is taken out and placed below.	
Algonkian.	Unconformity.			Unconformity.
Algonkian.	Lower Huronian, limestone, lower slate conglomerate, white quartzite, and gray quartzite.			Lower Huronian, except green chlorite slate, which is taken out and placed below.
	Unconformity.		Unconformity.	Unconformity.
Archean.	Keewatin series, greenstones and green schists (Thessalon group).	Unconformity.	Lower Huronian greenstones and green schists. (These are Logan and Murray's green chloritic slates).	Archean. Mareniscan greenstones and green schists. (These are Logan and Murray's green chloritic slates.)
Archean.	Laurentian series, granites and gneisses, not separated from Huronian granites.	Laurentian granites and gneisses.	Laurentian granites and gneisses intrusive into Lower Huronian, and in whole (Barlow) or in part into the Upper Huronian.	Archean. Laurentian granites and gneisses intrusive into Mareniscan schists.

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CHAPTER V.

PART OF QUEBEC NORTH AND WEST OF ST. LAWRENCE RIVER, INCLUDING THE ORIGINAL LAURENTIAN AND HASTINGS AREAS.

SUMMARY OF LITERATURE.

Logan,[1] in 1847, describes a metamorphic series of rocks between Ottawa and Mattawa rivers, which, in its highly crystalline character, belongs to the order named by Lyell Primary. They are called metamorphic because their aspect is such as to lead to the theoretical belief that they may be ancient sedimentary formations. A red syenitic gneiss, in which hornblende and mica are arranged in a parallel direction, is the predominant rock. The thickness of the gneiss is not ascertained. South of the Mattawa and Ottawa are important beds of crystalline limestone interstratified with the gneiss in a conformable manner, although this conformity would not be seen in a small area because of the minor complicated contortions. One section at High Falls, on the Madawaska, has a thickness of 1,351 feet, and consists of gneiss, crystalline limestone, and a small amount of micaceous quartz rock, the gneiss greatly predominating. The areas which bear limestone are so distinct that they are placed as a separate group of metamorphic strata, supposed from their geographical position and general attitude to overlie the syenitic group conformably. Both of the metamorphic groups are frequently traversed by dikes and veins, including those of a granitic and pyroxenic character. From the vicinity of Quebec the limestone group ranges along the St. Lawrence, a distance varying from 10 to 20 miles, reaches the seigniory of Argenteuil, where it makes a turn toward the valley of the Ottawa, is seen above Grenville, and is last seen about halfway between Fort William and Joachim Falls, and at Portage de Talon, on the Mattawa. In the vicinity of Grenville the limestone is plumbaceous.

Logan,[2] in 1852, finds a metamorphic and gneissic series of widespread occurrence along the River du Nord and in the country to the west. The Potsdam formation rests unconformably upon the metamorphic series.

Murray,[3] in 1852, describes a metamorphic series along and north of the upper St. Lawrence. On the Thousand Islands are micaceous and hornblendic gneisses. Crystalline limestones, quartzites, and conglomerates are found on the mainland, and the latter is cited as decisive evidence of the metamorphic character of the series as a whole.

MURRAY,[4] in 1854, remarks that south of the Laurentian series are the more recent fossiliferous rocks. The Laurentian series consists of masses of micaceous and hornblendic gneiss and masses of interstratified crystalline limestone. Intrusive granite is found in the gneiss. The magnesian crystalline limestone layers, one 700 feet thick, are persistent. A section of gneiss, mica schist, and quartzite, all sometimes garnetiferous, and two belts of limestone, together 140 feet thick, make up a succession 1,369 feet thick at Birch Lake. In the series is a conglomerate, the matrix of which in one case is a limestone and the pebbles are quartz and feldspar. In another conglomerate are distinct pebbles in a talcose slaty matrix. These pebbles are sometimes distinctly rounded and flattened, the flat sides always lying parallel with the bedding. The pebbles vary from 5 or 6 inches in diameter to those so small as not to exceed the size of snipe shot.

LOGAN,[5] in 1854, applies to the series before called "metamorphic," underlying the fossiliferous formations of Canada, the name Laurentian series, because metamorphic is applicable to any series of altered rocks. The proposed name is founded on that given by Garneau to the chain of hills which they compose. Above the Laurentian series is the Potsdam sandstone.

LOGAN,[6] in 1857, describes the Laurentian formation for some distance north of Ottawa River, between rivers Rouge and du Nord. The rocks are found to be limestone, gneiss, and quartzite. The limestone formations are used chiefly in working out the structure, but even with this guide the work is very difficult on acount of the repetition of layers by folding and of lack of fossils. All of the above rocks are taken to be metamorphosed sediments. They are cut by eruptives, such as syenite, porphyry, and greenstone, which are older than the fossiliferous formations.

HUNT,[7] in 1857, states that stratified feldspathic rocks are closely associated with the crystalline limestones, which alternate with gneissoid and quartzose rocks of the Laurentide Mountains. These rocks, besides containing pyroxene, which passes over into hypersthene and a triclinic feldspar, contain, as accidental minerals, mica, garnet, and ilmenite.

MURRAY,[8] in 1857, finds Laurentian rocks largely exposed between Georgian Bay and Ottawa River. The rocks are red and gray gneisses, micaceous and hornblendic schists, quartzite, and crystalline limestone. On Lake Nipissing and its islands is found the Laurentian formation, consisting of gneiss, mica schist, hornblende schist, crystalline limestone, and, associated with this, beds of specular ore.

Limestones are also found along Muskoka River. The strata are everywhere more or less corrugated, in many places exhibiting sharp and complicated folding. They are intersected by quartzo-feldspathic and quartz veins. The Laurentian rocks of Georgian Bay are separated from the Huronian north of Lake Huron by a line running from the northwest side of Shibahahnahning to the junction of Maskanongi and Sturgeon rivers, its course being northeasterly.

LOGAN,[9] in 1858, in describing the Laurentian of Ottawa, thinks it probable that it can be divided into two great groups—one characterized by the presence of limestone and the other without limestone, and that the latter of these groups also will be capable of subdivision. Often interstratified with the limestones are bands of quartzite, which are heaviest near the junction of the limestone and the gneiss. The greatest mass of quartzite is beneath the limestone and is 400 feet thick. The limestones of the Laurentian are influenced in their strikes and dips by subsequent masses of igneous rocks. However, to these rocks as a whole, as well as to their equivalent throughout Canada, is applied the term Laurentian series, from the Laurentide Mountains, extending from Lake Huron to Labrador, which are composed of this rock.

LOGAN,[10] in 1859, gives an elaborate description of the distribution of the limestones along Rouge River. Two belts are found, regarded as interstratified with the gneisses. This latter rock is sometimes garnetiferous and occasionally is spoken of as the quartzite. The total thickness of rocks exposed on the Rouge is more than 22,000 feet, of which more than 5,000 is limestone.

LOGAN,[11] in 1860, finds three belts of limestone, which are associated with massive orthoclase gneiss, mica slate, hornblende rock, and quartz rock, together 15,000 feet thick. The calcareous bands are largely associated with labradorite, and beds of hornblende rock and quartz rock are often thickly studded with pink garnets. One of the beds of pure white quartz rock is a thousand feet thick. Certain fossil-like forms have been found which resemble *Stromatocerium*. The strata are very much folded.

LOGAN,[12] in 1863, gives a general account of the pre-Potsdam rocks, which are called Azoic and are divided into the Huronian series and the Laurentian system. In the Laurentian system are included anorthosite, orthoclase gneiss, granitoid gneiss, quartzite, hornblende schist, mica schist, pyroxene and garnet rocks, and limestones and dolomites. The anorthosites are composed of lime-soda feldspar, varying in composition from andesine to anorthite and associated with pyroxene or hypersthene. The orthoclase gneiss has a never-failing constancy in the parallelism of its mineral constituents, which, however, is sometimes obscure. This rock is usually very feldspathic and often coarse grained. With the feldspar and quartz are often mica and hornblende. The gneisses appear to attain several thousand feet in thickness, but are divided at unequal intervals by hornblende and mica schist, in which the stratification is more distinct. The quartzites are in considerable volume, two layers of which, nearly pure, have thicknesses, one of 400 and the other of 600 feet. The masses of limestone are generally very crystalline and coarse grained, but sometimes are saccharoidal. The bands of limestone are sometimes of great thickness. They are usually not pure, but contain many other minerals, among which are very frequently mica and graphite. Among the rarer minerals is chondrodite. The iron ore, which is mostly magnetite, is interstratified with or not far removed from the limestone bands. Associated with the limestones are dolomites, which, however, compose distinct beds.

There is not any special order in the masses, but beds of hornblende rock and hornblende schist are more abundant near the interstratified bands of limestone than elsewhere, and in the same neighborhood there is usually a more frequent repetition of beds of quartzite than in other parts. Garnet is sometimes disseminated in the micaceous and hornblendic gneiss and quartzite, but is commonly confined to the immediate proximity of the limestones. The limestones and gneiss beds as a whole are generally conformable to them. It often happens that a subordinate layer of gneiss will display contortions of the most complicated description. Notwithstanding the highly crystalline condition of the Laurentian rocks, beds of unmistakable conglomeratic character are occasionally met with. These generally occur in the quartzite or micaceous beds. The intrusives of the Laurentian consist chiefly of syenite and greenstones. The greenstone dikes are always interrupted by the syenite when they have been found to come in contact with it, and the latter is therefore of posterior date. A mass of intrusive syenite occupies an area of about 36 square miles in the townships of Grenville, Chatham, and Wentworth. It is cut and penetrated by masses of a porphyritic character, which are therefore of a still later date.

The Laurentian series stretches on the north side of the St. Lawrence from Labrador to Lake Huron, and occupies by far the larger portion of Canada. Its strata probably have very great thickness. To determine the superposition of the various members of such an ancient series is a task which has never yet been accomplished. The difficulties attending it arise from the absence of fossils to characterize its different members. Bands of crystalline limestones are easily distinguished from the bands of gneiss, but it is scarcely possible to know from local inspection whether any mass of limestone in one part is equivalent to a certain mass in another part. They all resemble one another lithologically. The dips avail but little in tracing out the structure, for in numerous folds in the series the dips are overturned, and the only reliable mode of working out the physical structure is to continuously follow the outcrop of each important mass in all its windings as far as it can be traced, until it becomes covered by superior strata, is cut off by dislocation, or disappears by thinning out.

Several sections are described in detail. The general section is as follows, in ascending order: Orthoclase gneiss, 5,000 feet; Trembling Lake limestone, 1,500 feet; orthoclase gneiss, 4,000 feet; Great Beaver Lake and Green Lake crystalline limestone, including interstratified beds of garnetiferous and hornblendic gneiss, 2,500 feet; orthoclase gneiss, the lower part having several bands of quartzite, 3,500 feet; Grenville crystalline limestone, 750 feet; orthoclase gneiss, 1,580 feet; Proctors Lake limestone, 20 feet; orthoclase gneiss, including quartzite, 3,400 feet; anorthosite, thickness (wholly conjectural) 10,000 feet; total, 32,750 feet. In the limestones are fossil-like forms which resemble *Stromatopora rugosa.* Accompanying the account of the Laurentian is a detailed map of it in parts of the counties of Terrebonne, Argenteuil, and Two Mountains.

The anorthosite probably overlies the Grenville series unconformably. It is remarked that if the two inferior limestone bands of the Grenville series disappear on reaching the margin of the anorthosite, the disappearance is conclusive evidence of the existence in the Laurentian system of two immense sedimentary formations, the one superimposed unconformably upon the other, with probably a great difference of time between them.

Logan,[12] in 1863, first describes a part of what was later called the Hastings series. In ascending order are found contorted gneiss and micaceous schists cut by red syenite veins. Above this comes crystalline limestone, and north of the village of Madoc, still in ascending order, occurs a somewhat micaceous schist, which contains numerous fragments of rock in character different from the matrix, some of them resembling syenite or greenstone. The pebbles are in places distinctly rounded.

Bigsby,[13] in 1864, states that crystalline limestones occur in bands from 50 to 1,500 feet thick at Gananoque, on the Lake of the Thousand Islands, and on the Mattawa. The bands of marble are tortuous, and between them are sometimes found corrugated seams of gneiss. Conglomerates and grits occur at Bastard, on the Ottawa, and at Madoc, near Lake Ontario. At the former place, between the beds of marble, is quartzose sandstone, with pebbles of calcareous sandstone and vitrified quartz. At Madoc village are interstratified marble and conglomerate, one being bluish micaceous schist, holding fragments of greenstone and syenite, the other being a dolomite with large pebbles of quartz, feldspar, and calcite. The occurrence of limestone, carbon, phosphorus, sulphur, and iron ore is accepted as proof of life. The Laurentian system as a whole consists of, (1) orthoclase gneiss, sometimes granitoid, with quartzite, hornblendic and micaceous schists, pyroxene, and garnet rock; (2) white crystalline limestone and dolomites in numerous thick beds, containing serpentine, pyroxene, hornblende, mica, graphite, iron ores, apatite, fluor, etc., and interstratified with bands of gneiss; (3) lime-feldspar rock, or anorthosite, containing hypersthene, ilmenite, pyroxene, hornblende, graphite, etc. These three groups are traversed by granitic and metalliferous veins.

MACFARLANE,[14] in 1866, describes the Laurentian rocks of several towns in the county of Hastings. The rocks here found include granite, granite gneiss, gneiss, petrosilex, conglomerates, and limestones. At Madoc are conglomerates consisting of pebbles, generally of quartzite, in a schistose matrix, lithologically not unlike some of the Huronian rocks.

LOGAN,[15] in 1867, states that the Hastings series is arranged in the form of a trough, and that to the east, and probably beneath them, are rocks which resemble those of the Grenville, and it is supposed that the Hastings series is somewhat higher than the Grenville. The Madoc limestone is overlain unconformably at several places by the horizontal Lower Silurian limestone. In Tudor the limestone is suddenly interrupted for a considerable part of its breadth by a mass of anorthosite rock, rising 150 feet above the general plain, which is supposed to belong to the unconformable Upper Laurentian.

VENNOR,[16] in 1867, gives the ascending section of Laurentian rocks in Hastings County as follows: Red feldspathic gneiss, 5,000 feet; dark-green chloritic slates, 200 feet; crystalline limestone, 2,200 feet; siliceous and micaceous slates, 400 feet; bluish and grayish mica slates, 500 feet; pinkish dolomite, 100 feet; micaceous limestone or calc schist containing *Eozoon*, 2,000 feet; green diorite slates, 7,500 feet; reddish granitic gneiss, 2,100 feet; total, 20,000 feet.

DAWSON,[17] (Sir WILLIAM), in 1869, states that the graphite of the Laurentian is scattered through a great thickness of limestones, and is found also in veins. In one bed of limestone 600 feet thick the amount of disseminated graphite must amount to as much as a solid bed 20 or 30 feet thick. The graphite is believed to be of organic origin because, first, it contains obscure traces of organic structure; second, its arrangement and microscopical structure correspond with those of micaceous and bituminous matter in marine formations of modern date; third, if of metamorphic origin, it has only undergone the metamorphism which is known to affect organic material of later age; fourth, it is associated with beds of limestone, iron ore, and metallic sulphides, presumably of organic origin.

VENNOR,[18] in 1870, in a report on Hastings County, describes the pre-Silurian rocks. The rocks are divided into three divisions, A, B, and C. A, the lower division, consists of syenite rock, granitic gneiss, 2,000 feet; fine-grained gneiss, sometimes hornblendic and passing into mica schist, 10,400 feet; crystalline limestone, 400 feet. B, the middle division, is of hornblendic and pyroxenic rocks, including diorite and diabase, both massive and schistose, 4,200 feet. C, the upper division, consists of crystalline and granular limestone, 330 feet; mica slates interstratified with dolomite, sometimes conglomeratic, with pebbles of gneiss or quartzite 1 to 12 inches in diameter, 400 feet; slate interstratified with gneiss, 500 feet; gneissoid micaceous quartzites, interstratified with siliceous limestone, 1,900 feet; gray micaceous limestone, 1,000 feet. Total, 21,130 feet. The syenite in certain localities has no apparent marks of stratification. Associated with the above rocks are deposits of iron ore. *Eozoon canadense* occurs in the topmost member of the upper division (C). Division B rests immediately upon A, but whether conformably or not is not determined, as the basal members of B are massive diorites and greenstones.

VENNOR,[19] in 1872, applies to the lowest division of the Hastings series (A) the term Laurentian, and the middle division (B) is placed as probable Huronian. The rocks of the upper group are found to lie unconformably upon the gneisses and crystalline limestones of the lower group, and it is probable that the middle group is unconformably below the upper and unconformably above the lower group.

VENNOR,[20] in 1872, reports on Leeds, Frontenac, and Lanark counties, Ontario. The granite of the gold-bearing rocks is believed to represent eruptions which took place probably toward the close of the Laurentian period, or at some time prior to the deposition of the rocks of divisions B and C, for, whenever these higher rocks are wanting, the Laurentian gneisses, quartzite, and limestone are cut by a network of veins.

VENNOR,[21] in 1873, gives an additional report on the counties of Frontenac, Leeds, and Lanark. The area is divided into western, middle, and eastern sections. In the western section the main mass of rocks is of granite, syenite, and coarse-grained and fine-grained gneisses. The red granites sometimes appear to be of later date than the white mica granites and even of the diorites of division B. Limestone was not observed. In a trough between two granite and gneiss areas are found diorite slates, micaceous and chloritic schists, pyroxenic rocks, conglomerates, dolomites, and sandy crystalline limestones. In one conglomerate the pebbles of quartz in a matrix of sand and mica are flattened out along the plane of bedding, so that those which in cross measurement are not more than half an inch broad have a length of 5 to 10 inches. In places in the conglomerate, instead of pebbles, are layers of vitreous quartz or quartzite and mica schist. The middle section is undoubtedly Lower Laurentian. The rocks met with include great thicknesses of gneiss, for the most part clearly stratified, with well-defined strike and dip; masses of hornblende rock and diorite, grading into slate or schist; large and important bands of crystalline limestones, and groups of calcareous strata associated with mica slates and workable masses of magnetic iron ore. These rocks are clearly interstratified. Apparently five distinct bands of crystalline limestone are met with, separated by reddish granitic and dark hornblendic gneisses. The rocks of the eastern section consist chiefly of gneiss, but associated with this are coarsely granular limestones. The horizontal limestones of the Lower Silurian by a fault are brought into abrupt vertical contact with the Laurentian gneiss.

VENNOR,[22] in 1874, further describes Frontenac, Leeds, and Lanark counties. The five belts of crystalline limestones mentioned in the previous report are described in detail. *Eozoon* occurs abundantly in places.

VENNOR,[23] in 1876, gives a further report on the rear portions of Frontenac and Lanark counties. Two sections are given, representing the limestones as interstratified with the quartzites and gneisses. The rocks are classified into five groups: I, Mica-schist group; II, Dolomite and slate group; III, Diorite and hornblende schist group; IV, Crystalline limestone and hornblende rock group; V, Gneiss and crystalline limestone group. A sixth group, described in a previous report, occupies the front portion of Lanark County. Each of the five groups has many subordinate phases of rocks; they occupy distinct and separate positions, but it is not known whether they represent one or more formations.

VENNOR,[24] in 1877, states that there is in eastern Ontario and the adjoining portions of Quebec an Azoic formation, consisting of syenite and gneiss(?), without crystalline limestone, in which there is but little indication of stratification. On it has been unconformably deposited a great system of gneisses, schists, slates, crystalline limestones, and dolomites, in the higher member of which *Eozoon* is found. The limestone occurs in four principal belts. Logan's Huronian and Upper Laurentian are both considered to belong to the second division, which is for the present called the Upper Laurentian. Interstratified with several of the bands of limestone are labradorite rocks. No evidence is found for making these a distinct system. The Huronian and Hastings series are simply an altered condition, in their westward extension, of the lower portion of the upper system.

VENNOR,[25] in 1878, reports on the counties of Renfrew, Pontiac, and Ottawa. Referring to the work of previous years, it is said that the rocks of divisions B and C of the Hastings series are really the western extensions of the diorites, hornblende schists, and mica slates of

Lanark and Renfrew counties—in other words, of groups I, II, and III; that these last have also been shown to be a low portion of the gneiss and limestone series—that is, of groups IV, V, and VI; and that these have always been looked upon as typical Laurentian. The conclusion is consequently reached that the Hastings series is not, as it has been considered to be, the most recent, but rather the oldest portion of this great system of rocks investigated. It is also clear that this great crystalline gneiss and limestone series rests upon a still older gneiss series, in which no crystalline limestones have yet been discovered. This series is the one referred to as division A, where limestones have been mentioned, but incorrectly. This occupies many hundreds of square miles between St. Lawrence and Ottawa rivers, and is the rock which forms the backbone of eastern Ontario and the nucleus around which have been deposited all succeeding formations. This, then, is undoubtedly Archean and Lower Laurentian, and consequently the crystalline limestones and gneisses constitute a series which would come in beneath Logan's Upper Laurentian or Labradorite series. Whether this latter exists as a distinct formation is doubtful. In each instance in which the crystalline limestones have been found in the interior of the gneiss country, these have been proved to occur in the superficial condition of shallow troughs, and not as bands interstratified in the gneiss itself.

The lower, noncalcareous Laurentian is a great series of crystalline rocks, not only highly metamorphosed, but most intricately contorted. In the entire area studied the gneiss and syenite are by far the most abundant rocks, while gneisses with interstratified crystalline limestones occupy but a comparatively limited area, and this only toward the margins of the former. The relative volumes of the two distinct sets of rocks—that is, the gneisses with the crystalline limestones—bear about the same relations to the volume of gneiss and syenite that the comparatively narrow belt of Silurian does in this section of country to both of these together.

There is thus in these old crystalline rocks a great noncalcareous division and a smaller calcareous one. The first of these may be further subdivided into a stratified and unstratified portion, of which the latter is undoubtedly the lower and older. As shown by the map, north and northwest of the line, at the base of the gneiss and limestone series, are numerous and repeated troughs of the lower member of this division, which separate out over the great fundamental gneiss system in a most irregular manner, and it is these that have given rise to the supposition that the older gneiss and syenite are interstratified with the crystalline limestone. The three great subdivisions in eastern Ontario are, then, first, a great gneissic and syenitic series without limestone; second, a thinner gneissic series with labradorites and limestones; and, third, Lower Silurian (Potsdam to

Trenton). The thickness of the upper series, exclusive of the fundamental gneiss, is placed tentatively as 50,000 to 60,000 feet. No attempt is made to estimate the thickness of the underlying gneiss and syenite series.

Wilkins,[26] in 1878, describes near the Grand Trunk station of Shannonville, about three-fourths of a mile north of the village, a gray and green slate conglomerate which much resembles the slate conglomerate of Lake Huron belonging to the Huronian system. The base of this rock is a schistose gray orthoclase with green hornblende and epidote, while the pebbles are of Laurentian gneiss, white and red micaceous and syenitic granite, syenite, felsite, dolerite, diorite, epidote, chlorite, and quartz, these masses being generally rounded, particularly the gneissic pebbles, and very rarely angular, while in size some exceed a foot in diameter and others are not over 2 or 3 inches. At Gibsons Mountain, 6 miles southwest of Belleville, occurs Laurentian porphyritic coarse-grained granitoid syenitic gneiss.

Selwyn,[27] in 1879, states that he thinks, without having personally examined the district, that it has been conclusively demonstrated that the Grenville and Hastings groups, consisting of limestones and calcareous schists holding *Eozoon*, with associated dioritic, felsitic, micaceous, slaty, and conglomeratic rocks, form one great conformable series, which rests unconformably upon a massive granitoid, syenitic, or red gneiss series, and is unconformably below the Potsdam or Lower Silurian rocks. The same may be said of the Huronian series of Georgian Bay, which at Lake Nipissing includes some labradorite gneiss, and it is very probable that a connection will eventually be traced out between these supposed greatly different formations like that now proved to exist between the Hastings and Grenville series. The Norian series is thought to be a part and parcel of the great crystalline limestone series. These anorthosites are believed to represent the volcanic and intrusive rocks of the Laurentian period, and if so, their massive and irregular and sometimes bedded appearance, and the fact that they interrupt and cut off some of the limestones, are readily understood. Chemical and microscopical investigations both seem to point to this as the true explanation of their origin. That they are really eruptive rocks is held by nearly all geologists who have carefully studied their stratigraphic relations.

Selwyn,[28] in 1884, finds from Pembroke to Wahnahpitae River, on the Canadian Pacific Railway, nothing but Laurentian, which consists of red, gray, and white orthoclase gneiss, black hornblende schists and mica schists, often garnetiferous, pyroxenic gneiss banded like *Eozoon*, and large bands of crystalline limestone. These rocks are all very distinctly stratified, and dip generally in an easterly direction at angles varying from almost horizontal to vertical.

Adams,[29] in 1889, finds that the massive and stratified varieties of the anorthosite in that part of the Laurentian area lying to the north of the Island of Montreal are really only different portions of one and the same mass. It is concluded that most, if not all, of the areas are of eruptive origin, since they are frequently found cutting the gneisses. Bands of crystalline limestone are found in the region.

Low,[30] in 1892, describes the Archean of Portneuf, Quebec, and Montmorency counties in Quebec. These rocks cover about 980 square miles, and are covered on the south by Cambro-Silurian limestones and shales. A rough section from west to east across the northern portion, through Lake Simon, at right angles to the strike, is as follows:

Section through Lake Simon, Quebec.

	Miles.
1. Dark schistose mica gneiss, interbanded with coarser red and gray mica gneisses	10
2. Fine-banded gray, pink, and red mica gneisses, and mica hornblende gneisses	10
3. Dark-gray garnetiferous hornblende gneiss	2
4. Fine-banded gray, pink, and red mica gneisses and mica hornblende gneisses	7½
5. Dark-green, basic, crushed granitic gneiss	1½
6. Coarse red and gray augen gneiss	2½
7. Fine-banded gneiss (2) and (4)	6
8. Coarse red and gray augen gneiss	6
9. Fine-banded gray and pink mica gneiss	14
10. Anorthosite	2
11. Fine-banded gray and pink gneisses	12

In this section the rocks are grouped in accordance with the predominating kind, although bands of other varieties are included in all of the rough divisions. Divisions 1, 2, 3, 4, 9, and 11 appear to have been originally clastic rocks, subsequently completely metamorphosed into schists and gneisses and subjected to great pressures, which have folded and twisted them so that their original horizontal succession is greatly obscured. The different bands are conformable and appear to grade into one another. Division 5 embraces rocks probably of igneous origin, which have been injected along a line of weakness between the banded gneisses and the coarser grained rocks of division 6. Divisions 6 and 8 are usually gneissic, but in many places are granitic. They appear to underlie the banded gneisses, and are either the remains of older beds that have been re-fused or original molten matter which has dissolved and floated portions of the banded beds, since fragments of them are inclosed in the coarser gneisses. The anorthosite is also igneous, having apparently been intruded in its present position after the formation of the banded gneiss with which it is in contact. This contact is not sharp in places, as the gneisses usually seem to have been infiltrated by basic feldspar material from the anorthosite, causing a gradual passage from one to the other. At one place in division 11 appears a band of highly crystalline limestone.

At many places the Trenton limestone is found directly in contact with the Archean rocks. The surface of the Archean rocks on which these newer beds were laid down had a rounded undulatory form, closely resembling the present exposed surface. The gneisses and the limestone present fresh, undecomposed surfaces. At various places between the Trenton limestone and the Archean is a thin layer of calcareous sand rock, resting in the hollows of the Archean surface, which holds Trenton fossils. In one place in the limestone is found a bowlder of gneiss 6 feet long, 4 feet wide, and 4 feet thick, which is supposed to have been dropped by floating ice.

SMYTH,[31] in 1893, describes pre-Cambrian diabase dikes cutting the granites and gneisses of the Admiralty group of the Thousand Islands, St. Lawrence River.

ADAMS,[32] in 1893, describes the anorthosite of Canada, and gives its relations to the surrounding rocks. The great mass of the Archean of Canada is composed of an orthoclase gneiss, which is in many places laminated, but is in large part little laminated, and probably of eruptive origin. Much of the laminated gneiss is probably sedimentary. In certain regions the laminated gneiss is interlaminated with crystalline limestones, quartzite, amphibolite, etc. This series is a higher part of the Laurentian, and was called by Logan the Grenville series; while the lower gneiss, which does not bear any of this rock, became later known as the Ottawa gneiss. The limestone, graphite, etc., are evidences of the existence of life during the deposition of the Grenville series, and this was the earliest life of the planet.

All of the minerals of economic importance occur in the Grenville series. The relations of the Grenville to the Ottawa series have not been certainly determined, but it is probable that the Grenville series lies discordantly upon the old gneiss, the upper series being sediments originally like those that are deposited to-day.

The anorthosite group, or Upper Laurentian of Logan, is composed of eruptive rocks belonging to the gabbros. It is characterized by a predominance of plagioclase, which frequently is the only mineral of the rock. The rock is hard and originally was completely massive. This original structure has been modified so as to take on an extraordinary cataclastic structure, which has also given the rock a schistose character. This is not ordinary dynamic metamorphism, but is caused by a movement of the rock mass while it was deeply buried and near its melting point.

The anorthosite, although so regarded by Logan, is not a distinct sedimentary geological formation, but cuts through both the gneiss and the limestone of the Laurentian. Its intrusive character is shown by the following facts: It is a plagioclase gabbro; it cuts across the Laurentian schists; it holds as inclusions blocks of gneiss; about its masses, forming girdles, are many characteristic contact belts. The areas of anorthosite are isolated and lie along the border of the Archean continent of that time, exactly as the volcanoes of to-day are along the continental borders. In the great interior area of Laurentian no anorthosite has been found. The formation is all pre-Cambrian, as shown by the fact that it lies unconformably below the Cambrian; and it received its metamorphism and was deeply eroded also before the Cambrian was deposited. Its relations to the Huronian have not been determined, but it probably does not belong to the Huronian period, but rather to the closing part of the Laurentian.

The several regions of anorthosite are described separately, that of Morin and Saguenay being most fully considered. The Morin area is surrounded by the Grenville series. In the Grenville series are interlaminated limestones, bands of which can be traced many miles. In many places there are thin layers of the gneiss within the limestone. The limestone is less resistant and more plastic than the gneiss. As a result of folding, the bands of gneiss have been broken up, producing irregular banded blocks, which are isolated in the limestone in such a manner as to give rise to extraordinary pseudo-conglomerates.

The Saguenay region is of great size—5,800 square miles. It is surrounded on all sides by the orthoclase gneiss, or Ottawa gneiss. The anorthosite of this district is more basic than that of the Morin district, the plagioclase being in many places labradorite or bytownite. That it is an intrusive is shown by the same facts as in the Morin area.

Ells,[33] in 1893, gives a description of the Laurentian of the Ottawa district. A reexamination of the Trembling Mountain section shows that, instead of its being a continuous ascending series, there are no fewer than three anticlines and their corresponding synclines, and the section is still further complicated by faults of very considerable extent. But one limestone was found—that of Trembling Lake, and this, instead of being interstratified with the orthoclase gneiss, is in the form of a syncline overlying this gneiss. This limestone at no point was observed to be more than 50 feet in vertical thickness.

In the region between the anorthosite area and Gatineau River the limestone in nearly every case occupies well-defined synclines separated by anticlines of the underlying gneiss. In this area it has been found impossible to trace any bands of limestone to any considerable distance continuously, the limestones being often local in development and lenticular in form.

In the limestone in certain places are masses of quartzose rock and crushed gneiss, presenting the aspect of a true conglomerate. As to the thickness of the gneiss, on Rouge River, the most favorable place found for measurement, the section gave a thickness of 10,000 feet beneath the limestone, if there is no break, but this figure may not be accurate, as faults and repetitions of strata may occur at several places.

Intrusive within the gneiss and limestone are the anorthosite and syenite masses of Grenville and Chatham, and other less conspicuous masses. No fewer than six or seven clearly distinguished periods of intrusion can be recognized. The augen gneiss of Rouge River is probably also an intrusive.

The succession in the district, as determined, is, in ascending order: (1) Reddish-gray gneiss without distinct signs of bedding or stratification, but with a foliated structure; (2) reddish orthoclase gneiss interstratified with hornblendic, quartzose, and garnetiferous gneiss and beds of quartzite, the whole showing a well-stratified arrangement of beds; (3) grayish and rusty gneiss passing gradually upward into the calcareous portion of the system, between the gneiss and the limestone, there being interstratifications of the two; (4) schistose, sericitic, chloritic, and micaceous schists of the Hastings series. Division 4 overlies the crystalline limestone, and is believed to represent the lower member of the Huronian system. This arrangement of the Laurentian accords very closely with that in New Brunswick as given by Bayley and Matthew. Unconformable upon the Laurentian of Ontario is the Paleozoic.

Adams,[34] in 1893, describes the typical Laurentian areas of Canada. The basement rock here found is the Fundamental gneiss. It is uniformly reddish or grayish orthoclase-bearing gneissoid granite, poor in mica, and bisilicates. The foliation is often due to movement in a plastic condition. Dark bands of amphibolite are not uncommon, and hornblendic and pyroxenic gneiss appears in some places. The Fundamental gneiss, so far as at present known, is a complicated series of rocks, for the most part of unknown origin, but comprising a considerable amount of intrusive material.

In certain parts of the Laurentian area, and notably in the Grenville district, the Laurentian has a different character. In the Grenville series the orthoclase gneiss is still the predominating rock, although it here has a greater variety of mineralogical condition and is frequently well foliated. Amphibolites, hornblende schists, heavy beds of quartzite, and numerous thick bands of crystalline limestones are all abundant and interstratified with one another. In the series are ores and a wide variety of minerals. In the limestone and associated rocks graphite is often widely disseminated, but it does not occur in the Fundamental gneiss. The areas occupied by the Grenville series, while together aggregating many thousands of square miles, are probably small as compared with those of the Fundamental gneiss. The Grenville rocks, though generally highly inclined, over some large areas are nearly horizontal, but even in these cases they have been subjected to great pressure.

As to the origin and relations of the Fundamental gneiss and the Grenville series, three views may be taken:

1. The Fundamental gneiss may be the remains of a primitive crust which was penetrated by great masses of igneous rocks and subjected to repeated dynamic movements. The Grenville series may be an upward continuation of the Fundamental gneiss under altered conditions, marking a transition from a primitive crust to normal sediments. Thus the two would form one practically continuous series. The general petrographical similarity of the two series, taken in connection with the more varied nature of the Grenville series, its frequent stratified character, and the presence in it of limestones and graphite indicating an approach to modern conditions and the advent of life, together with the difficulty of clearly separating the two series from each other and defining their respective limits, lend support to this view.

2. The Grenville series may be considered as distinct from the Fundamental gneiss and reposing on it unconformably, being a highly altered series of clastic origin, the Fundamental gneiss having some such origin as suggested above or being an older series of still more highly altered sediments. But as it is now thoroughly crystalline, there is no absolutely conclusive proof that even the Grenville series is of sedimentary origin. However, the series is in all probability made up, in part at least, and perhaps wholly, of sedimentary material, but as this is not absolutely shown, the proposal to separate it from the rest of the Laurentian and class it as Algonkian or Huronian seems premature.

3. The Fundamental gneiss may be considered as a great mass of eruptive rock which has eaten upward and penetrated the Grenville series, while the Grenville series itself represents a series of altered sediments of Laurentian, Huronian, or subsequent age. The worldwide distribution of the Fundamental gneiss (forming as it does, wherever the base of the geological column is exposed to view, the foundation upon which all subsequent rocks are seen to rest) is opposed to this view, as is also its persistent gneissic or banded character.

The anorthosite series is a gabbro, often regularly laminated and much altered, which is intrusive within the Fundamental gneiss and the Grenville series.

The Hastings series has a very local development. It consists largely of calc schists, mica schists, dolomites, slates, and conglomerates, thus containing much material of undoubtedly clastic origin. The whole district has been subjected to great dynamic action, some of the pebbles of the conglomerates being distorted in the most remarkable manner. This series may be equivalent to a part of the original Laurentian, may follow above the Grenville series, or may prove to be an outlying area of Huronian rocks folded in with the Laurentian.

The whole of the above series was cut by various acidic and basic rocks, metamorphosed, and folded before upper Cambrian time, since the Cambrian sediments rest upon them unconformably and contain fragments of the lower series which show that when deposited they were in their present condition.

The roche moutonnée surface of the eroded Laurentian rocks was impressed upon them in the first instance in pre-Cambrian time, for along the edge of the nucleus from Lake Superior to the Saguenay the Paleozoic strata may be seen to overlie such surfaces showing no traces of decay and similar to those exposed over the uncovered part of the area. To what extent the Cambrian, Devonian, and Silurian seas passed over the Laurentian can not be determined, but it seems probable that in Cambrian time a not inconsiderable part of the Archean nucleus was under water, as shown by various outliers of these rocks. What evidence there is indicates that the area in later Paleozoic, Mesozoic, and earlier Tertiary times was out of water, being subjected to deep-seated decay and denudation, culminating in the glaciation of Pleistocene time. These processes removed all but mere remnants of the Paleozoic strata.

Adams,[35] in 1894, gives a preliminary description of the area of sheet 118 of the Canadian Survey, an area of about 3,500 square miles, situated north of Lake Ontario, in the counties of Victoria, Peterborough, and Hastings. The whole area is occupied by the rocks of the Laurentian system, with the exception of the southeast corner, which is underlain in part by the Hastings series. In the surrounding eastern portions there is an abundance of crystalline limestone, and the rocks have all the characteristics of the Grenville series of Sir William Logan. In the northwestern part of the area the country is apparently occupied by gneiss alone. The relations of the Grenville series to the gneiss free from limestone has not yet been definitely determined, although the limestone and the associated gneiss seem in certain cases to partially inclose areas which contain no limestone. Throughout the area occupied by the Laurentian rocks the dips are uniformly in an easterly direction, usually at moderate angles. Only at one or two points have westerly dips been observed, and these are local. The relation of the Hastings series to the Laurentian is also as yet uncertain. One of the most marked characteristics of this district is the great development of pyroxenic and hornblendic rocks, among which many are, without doubt, of eruptive origin. There are also several large intrusive masses of granite and a very extensive mass of nepheline syenite. Otherwise the Hastings and Grenville series are not very unlike petrographically.

In the area south of that of sheet 118, in Dalton and the western part of Digby townships, is found reddish orthoclase gneiss with dark micaceous and hornblendic bands, which is cut in a complicated way by coarse-grained granite. In the eastern part of Digby Township and in Lutterworth and Galway townships are found crystalline limestones and the peculiar rusty weathering gneisses always associated with them. In the limestone districts occur various metalliferous ores.

Ells,[36] in 1894, states that the mica and apatite of the Laurentian of Canada are confined to a horizon composed of a series of gneisses which constitute the upper portion of the Laurentian siliceous rocks and which underlie the limestone proper. This horizon grades upward by regular passage through the interstratification of calcareous layers into the massive crystalline limestone formation.

Adams,[37] in 1895, describes a district of 3,500 square miles of pre-Cambrian rocks belonging to the Grenville series immediately east of the Original Laurentian area, described by Logan and Ells, and northwest of the city of Montreal. A subordinate part of the area about Trembling Mountain and another area to the west of St. Jerome are referred to the Fundamental gneiss. The Grenville series occupies the major portion of the district, but about 1,000 square miles are occupied by anorthosite, which occurs in one large area known as the Morin area and ten smaller masses. The Morin anorthosite incloses detached masses of the gneiss. There are also present in the district one mass of intrusive syenite covering an area of 36 square miles, and a much larger mass of granite in the northeast portion.

The Grenville series is composed of rocks in well-defined bands, the whole exhibiting a clear foliation, usually parallel to the banding. The series thus has a decidedly stratified appearance, similar to that presented by sedimentary rocks. The gneiss, which on the west side of the area dips at an angle of 40°, toward the east becomes nearly flat, often quite so, and these nearly flat gneisses extend to the north and east far beyond the limits of the map. Throughout this area of flat-lying rocks the gneisses with their interstratified limestones and quartzites are as highly crystalline as in the most highly contorted districts and have evidently undergone an extensive stretching or rolling out, resulting in the tearing apart of the less plastic bands and the flowing of the material of the more plastic bands into the spaces between the separated fragments.

Petrographically the rocks of the district are found to fall into four classes:

1. Anorthosites and granites of igneous origin. All gradations may be seen between the ordinary anorthosite and that in which the whole is granulated so as to resemble in appearance a saccharoidal marble. The whole rock thus moved under pressure like so much dough, its continuity being perfectly maintained. This is Professor Heim's "Umformung ohne Bruch," millions of little cracks taking the place of a few larger ones, and it is by this process that granites and many gneisses and other crystalline rocks, when deeply buried under great pressure and probably very hot, move and accommodate themselves to stresses. This, it will be observed, is quite distinct and different from the shearing accompanied by the development of new materials, which takes place under other conditions and probably nearer the surface.

2. Augen gneisses, leaf gneisses, granulites, and foliated anorthosites, genetically connected with the last group, and largely, if not exclusively, of igneous origin also. The structural characteristic of this class is the cataclastic or granulated one, formed by the mechanical breaking down of the web of the rock under movements induced by great pressure, which movements produce in the rock a foliation more or less distinct, according to their intensity.

3. A series of crystalline limestones and quartzites, together with certain gneisses usually found associated with them. In these rocks the granulated structure is very subordinate or entirely absent. They are characterized by very extensive recrystallization with the development of new minerals. These minerals have crystallized under the influence of the pressure which granulated the gneisses of the second class, and are not in any marked manner deformed by it. These gneisses also differ from the granites and gneisses of classes 1 and 2 in chemical composition, giving analyses almost identical with those of slates. Moreover, the rocks of this class are very frequently graphitic, and analyses show that the gneisses correspond in chemical composition more closely with slates than with granites.

4. Pyroxene gneisses, pyroxene granulites, and allied rocks whose origin is as yet doubtful.

With regard to the Grenville series, from the presence of numerous and heavy beds of limestone and quartzite, their prevalent banded character, the widespread occurrence of graphite, and the fact that the gneisses associated with the limestones and quartzites have the composition of sands and muds and not of igneous rocks, it is concluded that it is extremely probable that this is an altered sedimentary series which has been deeply buried, invaded by great masses of igneous rocks, and recrystallized. In places the Grenville sediments may have been mingled with the igneous rocks by actual fusion.

Ells and Barlow,[38] in 1895, describe the physical features and geology of the proposed Ottawa Canal between St. Lawrence River and Lake Huron. The proposed canal for several hundred miles traverses for the most part Archean rocks nearly at right angles to the strike of their schistosity or banding. The work of Logan, Murray, Lawson, Adams, and others of the important workers on the Canadian crystallines is briefly summarized.

The Grenville series of the Original Laurentian area probably illustrates the most perfect section of Laurentian rocks which we can yet recognize. This section shows various kinds of gneisses, foliated and stratified, with foliated and massive granites and syenites, pyroxenic, dioritic, hornblendic, and quartzose rocks, and quartzite and limestone. In the basal beds of the limestone and quartzite, supposed to constitute the upper member of the series, are interstratified bands of rusty quartzose gneiss, which from the available evidence is believed to form an integral part of the limestone series. This portion presents, in its banded arrangement of quartzose and calcareous rocks, the usual aspect of true altered sedimentary strata. The same well-banded arrangement is also visible in some of the directly underlying gneiss; but microscopic examination shows that in the great mass of this gneiss evidence of aqueous origin is wanting. Some portions of the igneous rocks are undoubtedly older than the limestones, and probably represent the lowest known portions of the earth's crust. Other portions are clearly established to be of more recent age than the crystalline limestone. The oldest gneisses are foliated rather than stratified, but in their foliation they underlie the regular series of stratified hornblende and other gneisses which occur frequently between the Fundamental gneiss and the crystalline limestone and quartzite series at the summit of the section. To this fundamental series may be assigned the rocks of Trembling Mountain, those forming the anticlines north of Lachute, rocks from various places throughout the Grenville district, and large areas at different places along the upper Ottawa River section. Concerning many of the intermediate gneisses, it may be said that, while in their general aspect they resemble stratified sedimentary rocks, their study under the microscope shows them to have presumably a different origin, so that it is possible that the true altered aqueous portion may be confined to the areas of crystalline limestone with the associated bands of quartzite and grayish quartzose and hornblende gneiss. The crystalline limestones are particularly developed along the Ottawa River section, from the vicinity of Deschenes Lake, west of Ottawa city, to the village of Bryson, in which section they are frequently cut by large areas of granitic and dioritic rocks. At one place, near the Chats, the limestone is overlain by a considerable breadth of Huronian-looking schists, etc., which have been described under the name of Hastings series. The limestone has its most westerly outcrop on the Ottawa in the vicinity of Coulonge Lake, a short distance west of Black River. From here west to the mouth of the Mattawa the limestone occurs as separate belts occupying synclines in the upper stratified gneisses.

The rocks along the route of Mattawa and French rivers to Lake Huron are chiefly those which have been regarded as Laurentian gneisses. There is very little of the crystalline limestone which forms such an abundant constituent of the Laurentian farther east, and this, as well as the apparent inferior position of the gneisses, according to their banding, caused them early to be placed at the very base of the geological series and called the Lower Laurentian series. Crystalline limestone occurs at Talon Lake, on the east shore of the Great Manitou or Newman Island, in the eastern part of Lake Nipissing, as well as on two of the small islands composing this group and on Iron Island. All the evidence seems to point to the fact that the limestone has been caught up in the gneisses during its eruption.

The foliation of the gneisses is produced either (1) by alternation of light and dark bands or (2) by the more or less parallel distribution of the component minerals. In many of the plutonic rocks, and particularly in the granites and similar rocks, there is a marked tendency for the bisilicates to aggregate themselves in certain belts or patches (called Auscheidungen in the granites). The result of pressure on a rock characterized by the presence of these masses would be the flattening of the dark areas into more or less lenticular areas. Again, many of the dark bands are seen to have had their origin as dikes, which have been intruded along the planes of foliation.

Bonney,[39] in 1895, states that the *Eozoon* of Côte St. Pierre is either a record of an organism or a very peculiar and exceptional condition of a pyroxene marble of Laurentian age, which is not a result of contact metamorphism in the ordinary sense of the term.

Adams,[40] in 1896, describes and maps the Laurentian area north of St. Lawrence River, in the northwest corner of the southwest sheet of the Eastern Townships map (Montreal sheet). This Laurentian area is a portion of the southern margin of the great northern Canadian area of Laurentian rocks. The area is about equally divided between the rocks of the Laurentian system and intrusions of anorthosite which break through them. The Laurentian [a] consists of red and gray orthoclase gneisses, presenting great variations in both structure and composition, with which are associated crystalline limestones, quartzites, and amphibolites. In certain parts of the area two divisions can be recognized in the Laurentian—an upper

[a] The term Laurentian is thus used as it was by Logan.

series, characterized by the presence of crystalline limestones, quartzites, and gneisses of sedimentary origin with a banded structure, called the Grenville series; and a lower series of gneisses in which no limestone, etc., occur and which possess a foliated rather than a banded structure, known as the Fundamental gneiss. Grenville rocks are recognized south of Rawdon and in the westerly portion of the St. Sauveur district. The Fundamental gneiss apparently occupies much of the St. Jerome district. However, it has been found impossible to separate the two series and delimit them on the map.

The composition of most if not all of the gneisses belonging to the Fundamental gneiss can be paralleled among the igneous rocks, and it is concluded that many of these gneisses, at least, were of igneous, probably of intrusive, origin. In the Grenville also some of the gneisses are of igneous origin. However, many are believed to be of sedimentary origin, for the following reasons: (1) They are associated with numerous and heavy beds of limestones and quartzite; (2) they have a prevailing banded character, accompanied by very extensive recrystallization; (3) graphite is of frequent occurrence in them; (4) chemical analyses show that they have the composition, not of igneous rocks, but of sedimentary sands and muds.

The quartzite is sometimes pure, but frequently holds garnet, sillimanite, or other minerals. The limestones are coarsely crystalline marbles, sometimes pure, but at other times including grains of quartz, pyroxene, phlogopite, graphite, and other minerals.

The anorthosite belongs to the gabbros, but is characterized by a great preponderance of plagioclase feldspar, which is often so abundant as to make up the entire rock. At its contact with the gneisses are many contact phases. The anorthosite has been squeezed and foliated, together with the gneisses which it cuts, and it is concluded that its intrusion antedated at least the termination of the great earth movements which affected the Laurentian in pre-Potsdam time. In proportion as the anorthosites exhibit granulation they become light colored, some of the most metamorphosed ones resembling marble in appearance, although chemically they do not differ from the less modified anorthosites.

On the upturned edges of the Archean rocks, both gneiss and anorthosite, the Potsdam sandstone and other Cambro-Silurian rocks repose in flat and undisturbed beds.

Adams,[41] in 1897, describes the Laurentian granitoid gneiss and granite of the Admiralty group of the Thousand Islands, Ontario. The granitoid gneiss is presumably derived by metamorphism from the granite. A large exposure of crystalline limestone on Island No. 18 resembles in all respects that of the Grenville series of the mainland adjacent.

Barlow,[42] in 1897, gives a further account of the results of work being carried on by himself and Adams in the counties of Hastings, Haliburton, and Renfrew, Province of Ontario. Many of the so-called conglomerates of the Hastings and Grenville series are believed to be autoclastic rocks or pseudoconglomerates which have resulted in the main from complex folding and stretching. Therefore such rocks can not be cited as evidence of the clastic origin of the Hastings and Grenville series, as has been done.

Adams and Barlow,[43] in 1897, give a general outline of geological work begun, but not yet finished, in the Laurentian of central Ontario, in the area of map sheets No. 118 and a portion of 119 of the Ontario series of geological maps, and indicate certain conclusions which seem likely to be reached concerning the origin and relations of the Grenville and Hastings series.

The Fundamental gneiss occupies the northwestern, by far the larger, portion of the area. It consists of igneous rocks closely allied to granites, diorites, and gabbros, all showing more or less distinct foliation.

The Grenville and Hastings series are principally exposed in the southeastern portion of the area, the Grenville series appearing in a belt adjacent to the Fundamental gneiss, and between the Fundamental gneiss and the Hastings series.

The Grenville series is composed principally of gneisses identical in character with the Fundamental gneiss, but it contains also, and is characterized by, a small quantity of altered sediments, chiefly limestone. Some varieties of the gneissic rocks may owe their origin to the partial commingling of the sedimentary material with the igneous rocks by actual fusion. The strike of the foliation of the rocks of the series follows, in a general way, that of the Fundamental gneiss. The Grenville series is believed to be a sedimentary series, later than the Fundamental gneiss, which has sunk down into, and been invaded by, intrusions of the latter series when this was in a semimolten or plastic condition.

The Hastings series is composed chiefly of thinly bedded limestones, dolomites, etc., cut through by great intrusions of gabbro, diorite, and granite. This series is believed to represent the Grenville series in a less altered form. That is, the Fundamental gneiss, upon which the Hastings series was originally laid down, having at a subsequent time been softened by the influence of heat, and having under the influence of dynamic action eaten into and fretted away the overlying Hastings series, gave rise to an intermediate zone of mixed rocks which constitutes the Grenville series. The Grenville series may, however, represent only a portion of the Hastings series, and the work so far done has been insufficient to determine the stratigraphical position of this portion. It seems probable that the age of the Hastings series will be shown to be Huronian.

The Grenville and Hastings series are unconformably overlain by, and disappear to the south beneath, flat-lying Cambro-Silurian rocks.

ADAMS,[44] in 1897, reports on the geology of a portion of the Laurentian area lying to the north of the island of Montreal.

A previous report [40] covers about the southeast quarter of this area, and in a general way the conclusions reached for this southeastern area are applied to the larger area under discussion.

The Archean geology is summarized by the author as follows:

1. The Archean rocks in this area are of Laurentian age [a] and are in part referable to the Grenville series and in part to the Fundamental gneiss.

2. The Grenville series contains gneisses, as well as limestones and quartzites, which are of aqueous origin, having the chemical composition and the stratigraphical attitude of sedimentary rocks. With these are intimately associated, however, other gneisses which are of igneous origin.

3. The Fundamental gneiss consists largely, if not exclusively, of igneous rocks in which a banding or foliation has been induced by movements caused by pressure.

4. Both series are penetrated by various igneous masses, of which the most important are great intrusions of anorthosite, a rock of the gabbro family, characterized by a great preponderance of plagioclase. This rock is in places perfectly massive, but generally exhibits the irregular structure which is so often observed in gabbros and which is brought about by a variation in the size of the grain or the relative proportion of the constituents from place to place. In addition to this original structure, the rock almost always shows a peculiar protoclastic, cataclastic, or granulated structure, which is especially well seen in the foliated varieties. This differs from the structure characteristic of dynamic metamorphism in the great mountainous districts of the world, having been produced by movements in the rock mass while this was still deeply buried in the crust of the earth and probably very hot—perhaps near the melting point.

5. The same granulated structure is also seen in all those gneisses which have been formed from massive igneous rocks by dynamic movements.

6. The fine-grained aqueous rocks of the Laurentian, on the other hand, have been altered chiefly by a process of recrystallization.

7. The "Upper Laurentian" or "Anorthosite group" of Sir William Logan does not exist as an independent geological series—the anorthosite, which was considered to be its principal constituent, being

[a] In the sense of pre-Cambrian or original Laurentian.

an intrusive rock, and its remaining members belonging to the Grenville series.

8. In all cases of supposed unconformable superposition of the anorthosite upon the Laurentian gneisses, which have been carefully investigated, the unconformity is found to be due to intrusion.

9. The anorthosites are probably of pre-Cambrian age, and seem to have been intruded about the close of the Laurentian.

10. The Canadian anorthosites are identical in character with the anorthosites associated with the Archean rocks of the United States, Norway, Russia, and Egypt. The Norwegian occurrences, however, are probably more recent in age than those of Canada.

Ells,[45] in 1898, sketches the development of geological work in the Province of Quebec.

Miller,[46] in 1898, describes the occurrence of corundum in gneiss, syenite, and quartz pegmatite of the Laurentian in the counties of Hastings, Renfrew, and Peterborough in eastern Ontario.

Ells,[47] in 1901, describes and maps the geology of the area of the Three Rivers sheet of the Eastern Townships map, Province of Quebec. Archean rocks occupy most of the northwestern portion of the area north of St. Lawrence River. A portion of this area, including anorthosite masses, had previously been described by Adams.[44]

The great mass of the rocks seen pertain to the Grenville series, rather than to the so-called Fundamental gneiss. The composition of the Grenville series, with its crystalline limestones and rusty gneiss bands, very closely resembles that met with in the lower Ottawa district, but the calcareous members are much less widely developed. There are also large areas of anorthosite, red granite, augen gneiss, and masses of green pyroxenic diabase. Quartzite is an important component of this series, and large areas of this rock, similar to that found along the Ottawa, are found associated with the gneiss as far north as the northern limit of the map sheet.

The definition of the so-called Fundamental gneiss is, as a matter of fact, not always possible in this district. If the latter appears at all it must be along the crests of some of the numerous north-south anticlines, which are generally low, the rocks over a large area being inclined at low angles. The prevailing gneiss is a grayish and hornblendic variety, generally quartzose, with frequent bands in which garnets are abundant.

The anorthosites are intrusive in the Grenville series. The Grenville series is correlated with the Hastings series and both are equivalent to the Huronian. The Fundamental gneiss is Laurentian.

Ells,[48] in 1902, maps and describes the geology of Argenteuil, Ottawa, and part of Pontiac counties, Province of Quebec, and portions of Carleton, Russell, and Prescott counties, Province of Ontario, covering most of what has long been known as the Original Laurentian, and summarizes previous work in this district. Archean rocks, occupying most of the area north of Ottawa River, are mapped as crystalline limestone, gneiss, quartzite, anorthosite, granite gneiss, and porphyry. In the text the limestones with the quartzites and gneisses associated with them are described as sedimentary and are classed as Grenville, and the underlying gneisses and granite gneisses are described as of igneous origin and are called Fundamental Complex, the author in this classification following previous writers. It is evident that the rocks of the Grenville series are decidedly newer than those of the Fundamental division. As for the numerous and often large areas of red granite gneiss, many of these undoubtedly are of more recent date than either of the others, since they clearly cut both the gneiss and the limestone. While in some points the newer granite gneiss presents features similar to the Fundamental division, as in the foliation of certain portions, there is, over large areas, a marked difference in their aspects in the field.

Osann,[49] in 1902, makes a detailed petrographic description of the crystalline rocks in the Original Laurentian area of the Ottawa Valley.

Adams,[50] in 1902, summarizes the present status of the geological mapping of the Haliburton and Bancroft areas, Ontario. The survey has shown that the northern half of the area mapped consists almost exclusively of granite gneisses of igneous origin, which would in all probability have been classed by Logan as Fundamental gneiss. The southern half of the area, on the other hand, consists chiefly of a series of very ancient sedimentary rocks, largely limestones, which rests upon the gneissic series, but which has been invaded and altered by it. Large areas of the sedimentary series have been so shattered and penetrated by the granite gneiss that a sort of breccia on an enormous scale has resulted. Great batholiths of the granitic rock arch up and break through the sedimentary series elsewhere, the latter being wrapped around the batholiths in great sweeping curves. The same batholith structure is observable in the northern gneisses also, and can be traced by the curving strikes of the foliation of the gneiss, but here the limestones have been swept away by erosion.

Graton,[51] working under Adams, in 1903, describes in detail the petrographical relations of the Grenville limestones and granite in the township of Glamorgan, Haliburton County, Ontario. His conclusions are of importance as bearing on the relations of limestones and gneisses over other extensive areas in eastern Canada, the Adirondacks, and New Jersey. The writer summarizes his conclusions as follows:

The district exhibits a development of Grenville limestone pierced by intrusions of gneissic granite, which contain masses of dioritic rock. Considerable deformation took place during the intrusion. Between the limestone and the granite is a highly brecciated zone, holding large amounts of lime-rich silicates, which are eminently characteristic of contact metamorphism. Diagenesis took place. To a great extent, however, the elements, other than the lime necessary for the formation of these minerals, came from the intrusion and its accompanying exhalations. The metamorphism, then, was largely also metasomatic. In the gray gneisses and in the granite are dark basic masses, which represent fragments broken off from the limestone series and floated away into the igneous mass. They have been still more highly metamorphosed than the rocks from which they came and have been more or less dissolved and changed in character by the granite. In other words, they have been partially "granitized." The gray gneisses, which have the composition of quartz diorites, may represent an intermediate phase of this "granitization" between the inclusions and the granite. This theory may account for the large amount of plagioclase feldspar found in the granite itself.

Haycock,[52] in 1905, discusses the geology of part of the county of Ottawa along Lievre River. This is a typical Laurentian area of granites, gneisses, and schists, including bands of limestone, quartzites, and gneisses of sedimentary origin. It is concluded that unevenness in original deposition appears the most natural way to account for the erratic distribution of the limestone. In one area evidence is in accord with the hypothesis of the unconformable superposition and subsequent infolding of the limestone with a gneiss and quartzite, the whole then being disturbed by the acidic intrusives. At another place the limestones seem to be interstratified with the gneisses and quartzites. The relations of the sedimentary rocks to the massive gneisses are unknown. The gneisses are regarded as of igneous origin, but whether older or newer than the surrounding rocks, or of contemporaneous origin, was not determined.

Johnston (J. F. E.),[53] in 1905, reports on the geology of part of the county of Ottawa along Lievre River, a part of the Original Laurentian area.

Ells,[54] in 1905, discusses the geology of a portion of eastern Ontario in the counties of Renfrew, Addington, Frontenac, Lanark, and Carleton. The rocks in this area may be roughly divided into several groups, as follows:

1. Granite gneiss and syenite, which apparently represent the oldest series, upon which the others rest.

2. Gneiss, often grayish or reddish gray, sometimes highly quartzose and garnetiferous, but of various shades of color, certain portions of which pass upward into limestones. Hastings series.

3. Amphibolites with schists, sometimes micaceous, sparkling and glistening, often containing garnets; at other times chloritic, horn-

blendic, or dolomitic, with altered slates and true conglomerates and limestones.

4. Granites and diorites, some of which are clearly intrusive and newer than the rocks which they penetrate.

Between the basement granite gneiss and the overlying Hastings series there is sometimes an apparently fairly regular sequence; at other times the limestone of the Hastings series occurs in bands intimately associated with the granite gneiss, while occasionally the schists rest upon this lower rock. From the fact also that the lower gneiss is apparently of igneous origin, while the members of the upper series are of sedimentary character, or at least large portions of these may be assigned to this category, an unconformity may be assumed. It would appear from the examination of the Hastings series over widely separated areas that there is a marked resemblance at many points, and that in fact most, at least of the limestones and associated schists, with gneiss, are repeated from point to point, forming basins of approximately the same horizon.

Adams and Barlow,[55] in 1906, map and describe the portion of the protaxis lying to the north of Lake Ontario. In this district there is a typical development of Logan's Grenville series. The area mapped is extensive, embracing about 4,000 square miles, and was shown to be underlain by a series of stratified or stratiform rocks consisting chiefly of crystalline limestones with subordinate bodies of amphibolite and certain gneisses probably of sedimentary origin. These are invaded by masses of granite and granite gneiss which northward constantly increase in number and extent until they run together and pass into the great and continuous body of Laurentian gneiss which forms the mass of the northern protaxis of the continent.

These granite gneiss intrusions have the form of batholiths, around which the sedimentary rocks sweep in a series of curves and between which they settle down. The granite batholiths adjacent to the intruded strata hold scattered through them fragments of the Grenville formation, which become smaller and less numerous on receding from the contact. This gneiss, however, when the cover has been completely removed, displays a foliation strike, which when traced out shows a series of lines curving around certain centers, which mark the foci of batholithic intrusion. The limestone series, where it is invaded by the granite, is on the margin fretted away into a species of filigree work, and becomes at the same time very highly altered.

There is distinct proof that under the influence of this invading granite the limestone in some places has been changed into an amphibolite, practically indistinguishable from that produced by the dynamic alteration of intrusive bodies of the gabbro found in the same district.

These granite intrusions form part of the typical Laurentian gneiss of the northern protaxis, which stretches far away in an unbroken mass toward the pole. The limestone, on the other hand, has in certain places been found in a comparatively unaltered condition, in which case it is fine in grain and dark grayish blue in color. Since the more metamorphosed varieties of the limestone series are in all respects similar to the Grenville series of the Original Laurentian district, it is believed that the Hastings limestone series is the equivalent of the Grenville series.

In addition to the limestone and amphibolite, etc., and the invading gneissic granite, an extensive development of nepheline syenite is found in this region. This rock lies almost invariably along the contact of the granite batholiths with the limestone, although it does not occur by any means continuously along this contact. The nepheline syenites are seen to eat into the limestone in many places and to hold inclusions of the limestone. Its manner of occurrence indicates that this nepheline syenite forms a peripheral phase of the granite intrusions. Like the granites, the nepheline syenite in places is found to have a very coarse-grained pegmatitic development. In these nepheline syenite-pegmatites at one locality, in the township of Glamorgan, individuals of nepheline more than a yard in diameter were found. At some points the magma is extremely rich in alumina, so much so that its crystallization has led to a development of a corundum syenite. Elsewhere the syenite contains lenticular veins or masses of sodalite, of large dimensions. The corundum syenite is now being worked extensively at Craigmont for corundum, while a short distance east of the town of Bancroft the sodalite syenite is being worked for the production of sodalite as an ornamental stone.

Adams, Barlow, Coleman, Cushing, Kemp, and Van Hise, in 1907, report on the correlation of the pre-Cambrian rocks of the Adirondack Mountains, the "Original Laurentian area" of Canada and eastern Ontario. See summary in Chapter X, section 1, The Adirondack Mountains.

Miller and Knight,[56] in 1907, find the Keewatin series of the Lake Superior region represented in southeastern Ontario by ancient rocks of like character. The Grenville limestones have been deposited on the surface of the Keewatin. Overlying the Grenville limestone unconformably are the Hastings series of conglomerates, limestones, and other sediments provisionally classed as Huronian. The Grenville limestones are regarded as having the same relations to the Keewatin greenstones as do the iron formations of the Lake Superior Keewatin.

Adams,[57] in 1908, discusses the general features of the Grenville series of eastern North America and shows that it covers an area of at least 83,000 square miles, making it the greatest development of limestone known in the pre-Cambrian of North America and one of the greatest limestone developments of any age. A representative section shows that 53.3 per cent of the series is limestone. The belief is reaffirmed that the Hastings series passes over imperceptibly into the more altered Grenville series. Within the Hasting series, as also probably in the "Grenville" phase of the same rocks, there are two series which are petrographically identical. These series, when worked out, should be distinguished by specific names, as upper and lower Grenville, or one may be termed the "Madoc series." It is conjectured that the series should be correlated with the Huronian rather than the Keewatin, and the increase in the amount of limestone toward the east side of the Lake Superior pre-Cambrian is cited as bearing on this question, but it is concluded that the Grenville series may be a distinct entity, separate from either and differing in age from both.

SUMMARY OF PRESENT KNOWLEDGE.

The districts of the region to be considered are the original Laurentian, the Hastings, and outlying districts.

ORIGINAL LAURENTIAN DISTRICT.

The original Laurentian district may be considered to cover the broad area of pre-Cambrian rocks which has been closely studied north of Ottawa and St. Lawrence rivers, between the cities of Ottawa and Montreal. Identical in lithology and closely related in structure is the area north and east to beyond St. Maurice River, included in the area covered by the two western sheets of the Eastern Townships map of the Canadian Geological Survey.

A granitoid gneiss, called the Ottawa gneiss or "Fundamental gneiss," occupies the larger part of the area. It is red or gray in color. It varies in coarseness, in relative proportion of constituent minerals, and in distinctness of foliation. It is poor in the iron-bearing minerals, but bands of hornblende gneiss and amphibolite are not uncommon. Other schistose rocks are occasionally found. Contained in this gneiss are considerable areas of intrusive material, of which granite and syenite are two of the most important kinds. The gneiss contains no material which is demonstrably of sedimentary origin, or even of surface origin, or any material which suggests metamorphosed sedimentary or surface volcanic material. Its lithological characteristics are those of modified plutonic rocks. It shows, both in the field and under the microscope, evidence of profound orogenic movements. It has no structure but foliation, or, when more than one variety of rock is present, a banded structure. The vast thicknesses which have been given for the gneiss are based upon the supposition that the foliation is bedding.

Within this great Ottawa gneiss complex are comparatively small areas, with prevailing north-south trend, of a series predominantly sedimentary called the Grenville series. In this series gneisses are still the predominant rocks, but they present a greater variety of mineral composition, are more frequently strongly foliated, and often occur as well-defined bands or layers, like strata of sedimentary formations. Chemical analyses of these gneisses by Adams show that they have the composition of shales and slates rather than that of the Ottawa gneiss; in particular, the former contain less alkalies than the latter. Adams estimates that in the area nearly 50 per cent of the Grenville consists of limestone. From this fact it may be inferred that a considerable part of the adjacent gneisses are sedimentary, because no known normal sedimentary succession would contain limestones in such amounts over a large area, the average proportion of limestone to other sediments derived from the alteration of average igneous rocks being much less. Interstratified with these gneisses in the Grenville are hornblende gneisses and schists, beds of quartz schists, and thick beds of crystalline limestone or marble. The gneisses are often strongly garnetiferous. The limestones, and sometimes the gneisses, are graphitic, and in certain places are so rich in magnetite as to furnish iron ores. The folding of the series is complex, the contortions of the gneisses and their infoldings with the marbles being remarkably intricate. At places bands of gneiss associated with the marble have been disrupted and autoclastic rocks produced. In many places these breccias closely resemble a conglomerate, especially when bands of gneiss have been broken within a marble. Even when the interstratified gneiss is brecciated the marble is often perfectly massive. Since in certain cases thick bands of gneiss have resisted pressure without fracturing, while other belts of gneiss immediately above, interstratified with the marble, have been broken into autoclastic rocks, it has been suggested that the breccias are basal conglomerates and that there is a structural break between the part of the series bearing the marble and the gneiss below. However, in all cases in which close study has been made these pseudo-conglomcrates have been traced step by step into the ordinary interlaminated set of gneisses, schists, and marbles.

According to Adams, the gneisses of the Grenville series are unlike the Ottawa gneiss in showing less granulated structure, but are characterized by extensive recrystallization, with the development of new minerals.

The Grenville series, consisting as it does of regular alternations of marbles, gneisses, and subordinate quartz schists, bearing graphite and iron ores, is believed to be a profoundly metamorphosed sedimentary series, although there has not been discovered anywhere in the region any other evidence of clastic characters. So profound have been the orogenic movements that the once rounded grains, and even the pebbles and bowlders, if they ever existed, have been wholly destroyed.

Both Logan and Ells have subdivided the Grenville series into formations, but their successions are not the same, and in Ells's final map of the area no division is attempted. While there is no doubt that several formations exist, the separation of them is exceedingly difficult on account of the complicated structure and the profound metamorphism. It follows that no accurate estimate of the thickness of the series has yet been made.

Anorthosite, intrusive into the Grenville series and the Ottawa gneiss, covers numerous areas, some of them thousands of square miles in extent. The anorthosite has been so profoundly modified by dynamic action as now to be regularly laminated over extensive areas. At many places there are gradations between the massive and laminated varieties. Various basic and acidic rocks are intruded along or across the lamination of the sedimentary series.

Resting unconformably upon the upturned edges of the deeply eroded pre-Cambrian rocks of the region are the little-disturbed Cambrian rocks.

The relations which obtain between the Ottawa gneiss and the Grenville series were long described as those of apparent gradation. The downward gradation was explained by Logan to be that of progressive metamorphism, the Ottawa gneiss as well as the Grenville series being regarded as sedimentary. The relations have been explained by Lawson by the subcrustal fusion of the Grenville series, thus producing the granite gneiss. Adams and Barlow, principally from their work on the portion of the protaxis lying north of Lake Ontario in the Hastings district, conclude that the granite gneisses are intrusions with the form of batholiths, around which the sedimentary rocks sweep in a series of curves and between which they settle down, the batholiths having arched up the overlying strata and risen through them by the process of overhead stoping.

In the Hastings district Miller and Knight find the "Grenville" limestone lying upon basic igneous rocks forming the basal series of the district, similar to the Keewatin series in the Lake Superior region. They note a resemblance of the limestones and associated igneous rocks to the iron formations and greenstones of the Keewatin of the Lake Superior region. They also find a later sedimentary series (principally Hastings), likewise containing limestone, unconformably upon the Grenville series. The question is naturally raised whether in the original Laurentian district similar series are present.

Nomenclature and correlation.—Originally all of the rocks of the original Laurentian district, including both the fundamental gneiss and the Grenville series, were referred by Logan to the "Lower Laurentian" and the intrusive anorthosite to the "Upper Laurentian," supposed to be sedimentary and separated from the "Lower Laurentian" by an unconformity. Later Canadian geologists ascertained the igneous and intrusive nature of the anorthosite and have restricted the term "Lower Laurentian" to the Ottawa gneiss and the term "Upper Laurentian" to the Grenville series. In 1897 Adams, Barlow, and Ells suggested that the Grenville series has a position similar to that of the Huronian of the north shore of Lake Huron, without implying identity in age, thus practically confining the term Laurentian to the Ottawa gneiss. Adams later suggested as an additional possibility that the Grenville might be correlated with the Keewatin. This is further suggested by Miller and Knight's work in the Hastings district. So far as present evidence goes, the Grenville series can not be certainly correlated either with the Huronian (Algonkian) or with the Keewatin (Archean). On the accompanying map (Pl. I) the Grenville area is colored as unclassified pre-Cambrian.

HASTINGS DISTRICT.

The Hastings district includes an area between Ottawa and St. Lawrence rivers southwest of the city of Ottawa, extending from Peterborough and Hastings counties on the southwest to Lanark and Renfrew counties on the northeast.

Occupying large portions of the district is the fundamental gneiss, consisting of igneous rocks closely allied to granites, diorites, and gabbros, all showing more or less distinct foliation.

With these are associated large areas of sedimentary rocks similar to those of the original Laurentian district, among which limestone is the most abundant rock. As in that district, there are interstratified mica schists and mica gneisses, hornblende schists and hornblende gneisses, quartz schists, and marble; mica slates are also found. There is, however, the great difference that in the Hastings area the metamorphism is much less intense and in certain places there are conglomeratic schists and gneisses. These may be seen in typical development about and between Madoc and Bridgewater. These conglomerates contain a great variety of pebbles, including granite, syenite, amphibolite, felsite, gneiss, marble, quartz, and jaspilite. The pebbles of the conglomerate vary from distinct, well-rounded ones to those which are flattened in a remarkable manner, in some cases being not more than a half inch broad and 5 or 10 inches long. Cut in certain directions, the rock containing these much flattened pebbles appears to be a perfect crystalline schist; cut in another direction, it is clearly a conglomerate with a schistose matrix. The greater diameters of the flattened fragments invariably accord with the direction of schistosity. The schist conglomerates grade at various places into nonconglomeratic crystalline schists or gneisses.

South of the road between Madoc and Bridgewater there is evidence of a considerable break between the conglomeratic rocks and the limestones and associated hornblende schists and felsites. Southward the conglomerate gradually becomes coarser and near its base contains very numerous fragments of hornblende schist, felsite, and limestone which unquestionably have been derived from these formations just to the south. It is thus clear that there is in this area a considerable break between the two parts of the sedimentary series. Miller and Knight hold that both parts carry limestone, making discrimination on a lithologic basis difficult. The upper of the two series they call Hastings and correlate with the Huronian, and the lower with the Keewatin. Adams and Barlow do not discriminate the two series, but regard the Hastings as a less metamorphosed part of the Grenville, as it is typically exposed in the original Laurentian district. How general the break is can be determined only by further study.

As to the relations which obtain between the granite gneiss series and the sedimentary series two questions need consideration—first, its relations to the upper sedimentary series, and, second, its relations to the lower series. Adams and Barlow believed that the granite gneiss series has batholithic relations with the limestone series, and as they did not discriminate the two series, they supposed this relation to obtain for both. However, the presence of abundant granite and gneiss pebbles of various kinds in the conglomerate of the upper series leads to the conclusion that the granite gneiss series was present before the deposition of the conglomerate, and if this be so it emphasizes the importance of the break in the sedimentary formations noted near Madoc and Bridgewater.

At one place in the district the international committee of geologists found an area of calcitic and chloritic ellipsoidal-weathering schists which resemble the Keewatin of Lake Superior. Miller and Knight later found the "Grenville" limestone to rest upon basic igneous flows.

Felsite, felsite breccia, and other volcanics are associated with the sedimentary rocks. These are extensive in area and are an important feature of the district. Also associated with the Hastings series are abundant augitic and hornblendic rocks, many of which are probably eruptive.

OUTLYING DISTRICTS.

The outlying districts have not been studied to the same extent as the original Laurentian and Hastings districts. However, it is known for the outlying areas as wholes that the predominating rocks are granites and gneisses similar to the Ottawa gneiss of the original Laurentian district and are to be classed as Laurentian under the definition of the international committee.[a] Basic igneous rocks and sediments are also present, in unknown but small quantity, except about Davis Strait, where there is an immense development of crystalline limestone or marble, in all probability referable to the Grenville series.

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[49] Notes on certain Archean rocks of the Ottawa Valley, by A. Osann. Ann. Rept. Geol. Survey Canada for 1899, new ser., vol. 12, 1902, pt. O, pp. 84.

[50] Haliburton and Bancroft areas, Ontario, by Frank D. Adams. Summary Rept. Geol. Survey Dept. Canada for 1901, 1902, pp. 145–148.

[51] On the petrographical relations of the Laurentian limestones and the granite in the township of Glamorgan, Haliburton County, Ontario, by L. C. Graton. Canadian Rec. Sci., vol. 9, 1903, pp. 38.

[52] Geology of part of the county of Ottawa, by Ernest Haycock. Summary Rept. Geol. Survey Dept. Canada for 1904, 1905, pp. 232–239.

[53] Geology of part of the county of Ottawa, by J. F. E. Johnston. Idem, pp. 239–250.

[54] Report on the geology of a portion of eastern Ontario, by R. W. Ells. Ann. Rept. Geol. Survey Canada for 1901, new ser., vol. 14, 1905, pt. J, pp. 89; to accompany map sheet No. 119.

[55] Summary prepared for this bulletin by Doctor Adams. The maps of this region (Haliburton and Bancroft sheets) were exhibited to the meeting of the Geological Society of America, at Ottawa, in December, 1905, and the report on this region was to go to press in the summer of 1906.

[56] The Grenville-Hastings unconformity and the probable identity in age of the Grenville limestone with the Keewatin iron formation of the Lake Superior region, by Willet G. Miller and Cyril W. Knight. Sixteenth Rept. Bur. Mines, Ontario, 1907, pp. 221–223.

[57] Recent studies in the Grenville series of eastern North America, by Frank D. Adams. Jour. Geology, vol. 16, 1908, pp. 617–635.

CHAPTER VI.

EASTERN TOWNSHIPS OF QUEBEC SOUTHEAST OF ST. LAWRENCE RIVER.

SUMMARY OF LITERATURE.

MURRAY,[1] in 1847, describes the metamorphic rocks of the Notre Dame Mountains. The more important varieties are slate and trap. It is not certain that these rocks do not belong to the fossiliferous formation.

LOGAN,[2] in 1863, describes the Quebec group at length. Metamorphic rocks of various kinds are mentioned, but these are all regarded as belonging to the fossiliferous series. In the fossiliferous formations east of the Notre Dame Mountains are veins and masses of intrusive granite.

SELWYN,[3] in 1879, gives observations on the stratigraphy of the Quebec group. This group is divided into three distinct groups of strata: First, the lower Silurian group; second, the volcanic group, probably lower Cambrian; and, third, the Crystalline schist group (Huronian?). The rocks composing the third group are chiefly slaty and schistose, embracing various schists, imperfect gneisses, micaceous dolomites, and magnesian limestones. The upper part of this series emerges from beneath the upper Silurian.

SELWYN,[4] in 1883, finds in the Stoke Mountains an igneous belt unconformably overlapped and covered by the fossiliferous beds of the Levis formation and by the Siluro-Devonian rocks; but between these volcanics and the more schistose rocks of the central axis, by which they are underlain, no unconformity has been detected. These volcanics are provisionally classed with the lower series—that is, pre-Cambrian, and probably Upper Huronian. In the Quebec series are found important masses of granite which are intrusive in the fossiliferous series. The stratified rocks in contact with them are disturbed and altered, the limestones converted into graphitic schists or crystalline marble, and the argillites into mica slates and chiastolite and staurolite schists, which are traversed by streaks and veins (dikes?) of granite. These granites are regarded as of Silurian or Devonian age. The alteration of the fossiliferous beds has gone so far as to suggest a resemblance to the crystalline rocks which have been referred to the Laurentian or Huronian.

SELWYN,[5] in 1883, in speaking further of the Quebec group, asserts of the upper metamorphic or volcanic group that neither a schistose nor a bedded structure can be accepted as proof of nonigneous origin, and that a massive lava flow is as likely, through pressure and metamorphism, to assume a schistose structure as are ordinary sedimentary strata. Much of the material of the upper part of the lower groups is of contemporaneous irruptive and eruptive origin, though for the most part, through cleavage and alteration, so changed in external and physical character as to cause these rocks to be classed as metamorphic, notwithstanding that they still closely correspond in chemical composition with recognized igneous and volcanic rocks, and differ essentially from any known ordinary unmixed sedimentary deposits. It is suggested that the upper volcanic group may represent the Keweenian.

ELLS,[6] in 1887, reports on the geology of a portion of the Eastern Townships. Placed in the Cambrian are a set of slates of various colors, sandstones passing into quartzites, quartziferous schists, and conglomerates in which are found no calcareous beds or fossils. The conglomerates are of two kinds; one is composed of pebbles of the ordinary kind—granitoid rocks, quartzites, slates, etc.; the other is composed largely of dioritic pebbles in a diorite paste, with intercalated beds of sandstones and grits, and may be regarded as an agglomerate. This series in places is certainly unconformable to the Cambro-Silurian system on the one hand, and on the other to the underlying ridges of crystalline rocks from the débris of which they are largely formed. These strata for the most part flank the ridges of crystalline schists and gneisses, but at other times are in intricately folded basins in them. These rocks resemble the gold-bearing series of Nova Scotia. When near to or cut by masses of granite the strata have developed in them crystals of chiastolite and staurolite.

The areas of crystalline schists, gneisses, and limestones, with serpentines and associated strata, are referred to the pre-Cambrian. The age of these rocks is inferred from their lithological character, from their position of apparent unconformity below the overlying series referred to the Cambrian, and from the fact that their débris is found in the latter series. The areas of pre-Cambrian rocks are four in number. In position and in the fact that they contain copper they closely resemble the copper-bearing rocks of New Brunswick and the Huronian of the Bruce mines. There is a similarity to the series in England and Scotland described by Hicks under the names of Dimetian, Arvonian, and Pebidian. Summing up it is said: Whatever may be the exact age of these altered rocks, their present aspect entitles them to be classed as very ancient sediments, although, in view of the great alterations which may result from intense regional metamorphism, there is no reason why many of the ordinary sedimentary rocks of Cambrian, Cambro-Silurian, or even Silurian age should not assume much of the character of these just described. It is now tolerably clear that the series under consideration constitutes the lowest of all the geological formations encountered in this portion of the province.

Both plutonic and volcanic rocks occur in the Eastern Townships, including granites and diorites, some of which are at least as late in age as Lower Silurian, although others are earlier, as is shown by the fact that fragments of them are included in the strata referred to the Cambrian. The sedimentary strata are altered at the contacts with these intrusives. These granites are, however, held by Selwyn to be metamorphic.

SELWYN,[7] in 1887, states that at the Bras Stream, about 3 miles from the Chaudiere River, is well exposed a contact of the crystalline series with the black slates, showing the same unconformable relations between the Cambrian and pre-Cambrian as on the Quebec Central Railway. The granites considered by Ells as intrusive are regarded as more probably formed in situ by the same metamorphic agencies that have altered the adjacent strata, and the so-called dikes are probably due to segregation; in fact, the latter are rather veins than dikes. The granites are then regarded as an effect of the metamorphosing agencies rather than the cause of the metamorphism.

ELLS,[8] in 1889, gives a second report on the geology of the Quebec group. Throughout the area of the rocks referred to the Lower Cambrian no fossils have yet been found, but they resemble the lower portion of the Cambrian of New Brunswick. The most that can be said of them stratigraphically is that they are intermediate between the chloritic and micaceous schists of the central anticline and the overlying rocks of the Sillery. These Cambrian rocks have certain beds which closely resemble those of the Potsdam age of the Sillery; on the other hand, it is not easy to separate them from the underlying pre-Cambrian schists, although at certain points there is a manifest unconformity between the two series, as is well shown between Broughton station and Harvey Hill, on the Quebec Central Railway; the regular strike of the underlying chloritic rocks being nearly east-west, while the overlying black slate, with which are associated beds of grayish limestone, at times strike nearly north-south. The difference in the character of the Cambrian and pre-Cambrian strata, together with the occurrence of a line of fault between the crystalline schists of the Sutton Mountain anticline and the slates and serpentines to the east, are the chief reasons for the separation of these two series into pre-Cambrian and Cambrian. The pre-Cambrian areas found are composed mostly of alternations of chloritic and micaceous schists. In certain localities, as at Les Saints Anges, are found micaceous black and gray slates, and quartzites with crystalline limestone, which may be Cambrian or pre-Cambrian. The areas of granite, diorite, and serpentine are described.

ELLS,[9] in 1890, states that the lowest beds of the Lower Cambrian contain in many places a very considerable thickness of conglomerates, the pebbles of which are without doubt derived from the underlying crystalline ridges which have been called pre-Cambrian. They are distinct in character from the pre-Cambrian of the anticlines, the latter being in all cases highly crystalline, while there is a sharply defined line, either of unconformable overlap or of fault, between the crystalline series and the slates and quartzites of what has been styled Lower Cambrian. This line of fault is to be seen at certain points, and is heavy; at others the slates occupy basin-like areas infolded in the schists, where the rocks pass at once from the black, gray, and purple slates to the highly altered schists. There are certain areas of mica schists and black slates which are apparently in the center of the anticline of Sutton or the Chaudiere. These probably represent a portion of the pre-Cambrian, but they are quite distinct from the ordinary black, purple, and gray slates and quartzites of the Chaudiere gold series.

ELLS,[10] in 1896, reports on the geology of a portion of the Province of Quebec comprised in the area covered by the southwest sheet of the Eastern Townships map (Montreal sheet), and describes pre-Cambrian rocks occurring to the east of St. Lawrence River. These occur along the axis of the Sutton Mountain range and in the anticline east of Memphremagog Lake near Fitch Bay.

The crystalline schists of the Sutton Mountain range may be divided into two principal portions, (1) the gneissic, micaceous, quartzose, and talcose schists of the central portion, or that in which the axis of the anticline is situated, and (2) a series of green, chloritic, schistose rocks, with the characters of altered dioritic rocks, constituting an easily separable portion, flanking the central area of schists to the west and extending from the Vermont boundary to the St. Francis in the vicinity of Richmond. This second or chloritic division is recognized also at various points on the eastern slope of the range, but it does not there present so marked a development. The age of the green schistose dioritic portion is doubtful, but it appears to coincide to some extent with the Volcanic group of Selwyn,[a] which he supposed to be probably Lower Cambrian or Huronian.

East of Memphremagog Lake, near Fitch Bay, the pre-Cambrian rocks are schistose, altered, dioritic rocks, occasionally with micaceous bands, and often containing clear grains of quartz. These rocks are apparently allied to the green chloritic schists of the west slope of

[a] Selwyn, A. R. C., Stratigraphy of the Quebec group and the older crystalline rocks of Canada: Rept. Geol. Survey Canada, 1877–78, pt. A, p. 3.

the Sutton Mountain range, and are placed on the map as doubtfully Huronian.

Cutting the pre-Cambrian rocks, and possibly also later sediments, are rocks having a considerable variety, such as granites, syenites, diorites, diabases, serpentines, traps, etc., evidently of different ages. It is probable that the age of the granites is not far from the close of the Silurian period.

Dresser,[11] in 1902, concludes: (1) That at least the greater part of the pre-Cambrian or crystalline belts of the Eastern Townships of Quebec is of igneous, not sedimentary, origin, as has been hitherto supposed. (2) That these rocks are allied to the volcanics of South Mountain, Pennsylvania, especially to the basic types, and indicate the continuance of this class of rocks throughout the Appalachians, as was suggested by Williams. (3) That the sediments of the region, which possibly all belong to the Quebec group, were deposited between and upon the preexisting ridges of igneous material, which are now being uncovered by denudation, while the intervening valleys still remain deeply filled.

SUMMARY OF PRESENT KNOWLEDGE.

The following summary has been prepared by John A. Dresser:

The pre-Cambrian of the Eastern Townships of Quebec south of St. Lawrence River comprises three principal areas, which form narrow belts conforming to the Appalachian folds. They are designated the Sutton Mountains, the Stoke Mountain, and the Lake Megantic areas, the first and second being extensions of the Green Mountains of Vermont, the third, a continuance of the White Mountains of New Hampshire. These belts consist principally of ridges of volcanic rock of the quartz porphyry andesite series, which are the oldest rocks of the region. They are highly altered and have long been mistaken for sediments, and have been correlated accordingly. They represent the chloritic, epidotic, nacreous, and much of the micaceous schists, as well as considerable portions of the argillites of the earliest reports.

In position they apparently belong to the more westerly of the volcanic belts pointed out by the late G. H. Williams as running throughout the Appalachians. On the ground of their similarity to the other rocks of this belt they are thought to be of pre-Cambrian age.

Associated with these volcanics are dolomites, quartzites, graywacke, and mica schists, which in many places appear to be older than the Paleozoic strata of the basins intervening between the ridges of volcanics. In other places they can not be separated from those rocks. On the whole, it can at present only be said that, while it is possible and even probable that there are pre-Cambrian sediments in this region, it can not yet be regarded as proved that such is the case.

All these rocks, together with associated Paleozoics, were included in the Quebec group of Logan and Murray and believed to be of sedimentary origin.

NOTES.

[1] The metamorphic rocks of the Notre Dame Mountains, by Alexander Murray. Rept. Prog. Geol. Survey Canada, 1845–46, pp. 111–114.

[2] Report of progress of the Geological Survey of Canada from its commencement to 1863, by W. E. Logan, pp. 983, with an atlas.

[3] Report of observations on the stratigraphy of the Quebec group and the older crystalline rocks of Canada, by A. R. C. Selwyn. Rept. Prog. Geol. Survey Canada, 1877–78, pp. 1–15A.

[4] Notes on the geology of the southeastern portion of the Province of Quebec, by A. R. C. Selwyn. Rept. Prog. Geol. and Nat. Hist. Survey Canada, 1880–1882, pp. 1–7A.

[5] The Quebec group in geology, with an introductory address, by A. R. C. Selwyn. Proc. and Trans. Roy. Soc. Canada, 1882–83, vol. 1, sec .4, 1882, pp. 1–13.

[6] Report on the geology of a portion of the Eastern Townships of Quebec, relating more especially to the counties of Compton, Stanstead, Beauce, Richmond, and Wolfe, by R. W. Ells. Rept. Prog. Geol. and Nat. Hist. Survey Canada, 1886, new ser., vol. 2, pp. 1–70J, with a colored geological map.

[7] Idem, footnotes, pp. 23J, 29J, 36J.

[8] Second report on the geology of a portion of the Province of Quebec, by R. W. Ells. Ann. Rept. Geol. and Nat. Hist. Survey Canada, 1887–88, new ser., vol. 3, pt. 2, pp. 1–120K.

[9] Personal communication.

[10] Report on a portion of the Province of Quebec, comprised in the southwest sheet of the "Eastern Townships" map (Montreal sheet), by R. W. Ells. Ann. Rept. Geol. Survey Canada, 1894, vol 7, pt. J, 1896, pp. 1–92.

[11] A petrographical contribution to the geology of the Eastern Townships of the Province of Quebec, by John A. Dresser. Am. Jour. Sci., 4th ser., vol. 14, 1902, pp. 43–48.

See also The copper-bearing rocks of the Eastern Townships, Quebec. Summary Rept. Geol. Survey Canada, 1903, vol. 15, pt. AA, 1904, pp. 146–149, with sketch map. A study in the metamorphic rocks of the St. Francis Valley, Quebec. Am. Jour. Sci., 4th ser., vol. 21, 1906, pp. 67–76.

CHAPTER VII.

NEW BRUNSWICK, NOVA SCOTIA, NEWFOUNDLAND, AND GASPE PENINSULA.

SECTION 1. NEW BRUNSWICK.

SUMMARY OF LITERATURE.

SOUTHERN NEW BRUNSWICK.

Gesner,[1] in 1839, gives many details as to particular localities in southern New Brunswick. The succession of rocks below the Old Red sandstone is argillaceous slate and granite. The volcanic rocks of the Bay of Fundy are of different ages.

Gesner,[2] in 1840, gives a continuation of his study of the previous year.

Gesner,[3] in 1841, describes the geology of the county of St. John more fully than in previous reports. The syenites occupy a large area, and against these lean the slates, graywackes, and limestones parallel to the coast of the Bay of Fundy, but there is a group of more schistose rocks containing no organic remains which dip toward this ridge. These latter are evidently Primary, while the graywackes and graywacke slates are Cambrian or Silurian. It is certain that a part of the granitic and syenitic rocks which have been regarded as Primary really belong to a later age.

Gesner,[4] in 1842, finds that the graywackes and slates provisionally correlated with the Cambrian were deposited prior to the elevation of the granitic, syenitic, and trappean masses upon which they rest, as they are fractured in all directions by dikes and extensive elevations of those rocks.

Gesner,[5] in 1843, places the granite, syenite, trap, and serpentine in the unstratified rocks. To the Cambrian system are referred a series of graywackes and clay slates which are sometimes conglomeratic. These rocks extend from the American boundary nearly to Bathurst, and in them organic remains occur.

Johnston,[6] in 1850, in a report on the Province of New Brunswick, gives a map by Robb in which the crystalline rocks are outlined as granite, gneiss, mica slate, and trap rocks.

Bailey, Matthew, and Hartt,[7] in 1865, in observations on the geology of southern New Brunswick, give a résumé of the work previously done. Of the fifteen different groups of rocks, the lowest consists principally of granite, gneiss, mica schist, and thick beds of crystalline limestone. This is the Laurentian or Portland group. Resting upon the Portland group is the Coldbrook group, belonging to the Huronian division of the Azoic system, also thick deposits of altered slate of a volcanic character, surmounted by conglomerates. The Coldbrook group is succeeded by the St. John group, which contains no coarse material and is regarded as equivalent to the Potsdam or Primordial of New York. Above the St. John group is the Bloomsbury group, of volcanic character, such as basalt, amygdaloid, and trap rock, which are associated with conglomerates and slates destitute of fossils. Geographically separated from the above groups are the rocks of Kingston, which are regarded as Upper Silurian, and the mica schists of Queens County, which may be Cambrian. Scattered through all the above are igneous rocks, such as granite, syenite, porphyry and trap, which may occur associated with rocks of any age. The Portland group is in almost entire conformity with the Coldbrook group. The lithological resemblance of the Coldbrook group (7,000 feet thick) with the Huronian is very close. The presence of graphite in the Portland and St. John groups is regarded as evidence of life.

The extreme metamorphism of the Portland group is evidence of its great antiquity. This age would never have been doubted were it not for the intimate association and conformity with the beds of the overlying groups, which are unquestionably Upper Devonian, and the Portland was supposed to represent either a portion of the Lower Devonian or possibly the upper part of the Silurian. During the deposition of the Azoic and Silurian ages a long period of repose prevailed, broken only by the volcanic activity of the Coldbrook group. The Bloomsbury rocks, associated with rocks unquestionably of Upper Devonian age, are referred to the same horizon. At one place the Coldbrook group overlies the St. John, its position being due to a reverse folding caused by a ridge of eruptive syenite. The Kingston group is provisionally referred, on its general lithological character and stratigraphical relations, to the Upper Silurian, although Lower Silurian and Lower Devonian beds may occur.

Matthew,[8] in 1865, correlates the Portland series, which includes limestone, syenite, gneiss, conglomerate, slate, and graphitic shale, with the Laurentian, first, because of its lithological characteristics, and second, because it is unconformably overlain by great thicknesses of deposits similar to the Huronian series of Canada. The Coldbrook Huronian group is conformable with the Lower Silurian St. John beds, although there is a marked contrast between the formations, the former containing conglomerates and volcanic products, but the latter none.

Hind,[9] in 1865, in a geological sketch of the Province of New Brunswick, finds no rocks older than the Lower Silurian. The belts of granite are regarded as of Devonian age, being apparently thrust up through the Lower Silurian and Devonian strata before the beginning of the Carboniferous epoch. The Quebec group includes gneiss, anorthosite, mica schist, hornblende rocks, diorite, various schists, and other crystalline rocks.

Matthew and Bailey,[10] in 1870, divide the metamorphic rocks of New Brunswick and Maine into, first, a Laurentian series, which consists of gneiss, often granitoid in aspect, including (1) crystalline limestone and interstratified beds of quartzite and diorite, and (2) a Labradorian or Upper Laurentian series, which consists of feldspar rock associated with hypersthene and magnetite; and, second, a Cambrian or Huronian series. The granites of St. Johns River are of Devonian age.

Bailey and Matthew,[11] in 1872, find the Laurentian system to have a rather widespread distribution. The rocks are placed in the Laurentian because they are older than the Silurian rocks, which contain a Primordial zone, as well as on account of their general lithological resemblance to the ancient rocks of the Laurentian system. The Laurentian is separated from the Primordial beds by an accumulation of trappean and tuffaceous strata which is supposed to be of Huronian age. The lower division of the Laurentian consists of diorites, syenite, granitoid gneiss, etc., while its upper division consists of crystalline limestone with diorite at intervals, greenish gray gneiss, quartzite, argillite, and slate conglomerate. The contact of the granite with the schistose rocks is peculiar. In the granite are long irregular blocks of the schistose rock. Their occurrence suggests either a softening of the older series through metamorphism subsequent to the deposition of the upper series, or else the intrusive character of the granites. One section of gneiss and granite in the Lower Laurentian has a thickness of 12,600 feet. The maximum thickness of limestone and quartzite of the Upper Laurentian is not more than a thousand feet.

In the Huronian series are placed the Coldbrook, Coastal, and Kingston groups, which together occupy a wide area. The Coldbrook group at several points was observed to rest upon the gneissic and granitic rocks referred to the Laurentian system, and in turn to be conformably overlain by the slates of the St. John group containing Primordial fossils. The Coldbrook group consists of diorite, chlorite schists, black slates, micaceous shales, argillites, gneissoid rocks, and other varieties. The rocks of the Coastal group consist of felsites and conglomerates, gray limestones and gray clay slates, gray chloritic grit and schists, micaceous slate and gray dolomite, green and red clay slate, and diorite. The Kingston group consists of shales, felsites, diorites, and argillites. In Grand Manan are various crystalline rocks which are not definitely referred to any period, but are compared to the Huronian. The Devonian and Huronian rocks are folded together, but no evidence is seen of unconformity between the two series. The Mascarene series in general aspect resembles the Huronian series of St. John and King counties. Intrusive granites are found at many points. In general the contacts of these granites with the surrounding rocks are not found, and their age is thus unknown.

The diorites and schists of Bloomsbury Mountain, formerly supposed on stratigraphical grounds to be more recent than the Huronian, resting upon the St. John group and overlain conformably by the Devonian sandstones, are now regarded as Huronian on lithological grounds, being probably brought up by a fault. At Musquash Harbor and at Ratcliffe's mill stream green subcrystalline schists rest conformably upon the Primordial strata, but the latter are believed to be overturns and the former Huronian.

The rocks of the Coastal group at several points overlie Upper Silurian or Devonian strata. They were formerly described as Devonian; but as Hunt finds them similar to the Huronian in lithological character, they are so referred, and the apparent inferior position of the Devonian is supposed to be due to a dislocation. Accidental intercalations of Upper Silurian and Kingston strata are found.

Bailey,[12] in 1872, describes the rocks of the greater part of Grand Manan as consisting of Triassic trap. Upon its east side are, however, found metamorphic rocks, which may belong to different series; but none are believed to be more recent than the earliest Primordial Silurian, while some of them may be Huronian.

Matthew and Bailey,[13] in 1876, place the Mascarene and Kingston series, the latter of which was previously considered Upper Huronian, in the Upper Silurian on account of fossils discovered in them.

Bailey and Matthew,[14] assisted by Ells, in 1877, in observations on southern New Brunswick, provisionally refer the Coldbrook group, formerly considered as Laurentian, to the Huronian. The granites are separated from the stratified formations of the Coldbrook group.

Matthew,[15] in 1878, refers as doubtfully belonging to the Laurentian the slate formation of Charlotte County, formerly described as Coastal rocks and placed in the Huronian. In the Kingston series, more recent than the Coastal, are rather crystalline rocks which are believed in part to belong to the Upper Silurian, but, like the Coastal rocks, are of uncertain age. The crystalline mica schists, hornblende schists, gneisses, diorites, etc., of Grand Manan combine in characters the two belts of Kingston rocks and those of certain Upper Silurian strata.

Bailey and Ells,[16] in 1878, find in the Caledonia Mountains of Albert and Westmoreland counties chloritic and talcose slates associated with beds of grit and conglomerate, which are regarded as probably of Huronian age.

ELLS,[17] in 1879, finds in Albert, eastern Kings, and St. Johns counties pre-Silurian rocks, which are placed in the Huronian and Laurentian. The older series is said to consist of syenite, felsites, feldspathic quartzites, and limestones. In many places are transitions from the slates, through schists, felsites, and gneisses, to syenites. The newer series consists of felsitic, siliceous, brecciated, and ash rocks at the base, with talcose, chloritic, and older schists, ash rocks and purple grits, and conglomerates. The second group lies unconformably upon the rocks of the first.

BAILEY,[18] in 1879, divides the pre-Silurian rocks of southern New Brunswick into four divisions on lithological grounds. The first are syenitic, feldspathic, and gneissic rocks; the second, limestones and dolomites, with others. These two divisions are regarded as belonging to the Laurentian. The third is a felsite-petrosilex group which comprises sandstones and conglomerates, as well as amygdaloidal ash rocks and ash conglomerates. This is the Coldbrook group of the earlier reports and is regarded as a lower member of the Huronian system. The fourth division is a schistose, chloritic, and micaceous group, comprising among other rocks conglomerates, clay slates, quartzites, ash rocks, amygdaloids, etc., and is regarded as the upper member of the Huronian system. The passage from division 2 to division 3—that is, from the Laurentian to the Huronian—is a gradual one, as the two groups are intimately associated.

Placing the Upper Coldbrook group as pre-Silurian, the unconformity of this group with the Silurian is in general marked. The Primordial beds sometimes rest upon division 3 and sometimes upon division 4; they contain in places coarse basal conglomerates, and appear to have been originally deposited among the hollows of the Huronian series. South of Bloomsbury Mountain, and on the main stream of Black River and the adjacent region, the Huronian rocks are associated with the Devonian, and the two formations accord almost exactly both in strike and in dip, the Devonian being included among the Huronian rocks. But in addition to the fact that the conglomerates of the former are largely made up of the débris of the latter, there are points in which this accordance is clearly wanting. The discordance is pretty well seen at the east branch of Black River.

MATTHEW,[19] in 1879, finds the Kingston series to exhibit a strong resemblance to the Huronian formation of St. John County, but it is regarded as Silurian on paleontological grounds.

BAILEY, MATTHEW, and ELLS,[20] in 1880, give a general review of their work in southern New Brunswick, which covers an area of about 6,000 square miles. The rocks comprised under the pre-Cambrian include the Laurentian of 1871 and the three former divisions of the

Huronian—Coastal, Coldbrook, and Kingston. Of the relations of the upper members of the Laurentian, mica schist, limestone, and fine gneiss, to the main body of coarse syenite and syenitic gneiss constituting the Lower Laurentian nothing further is known than is contained in the report of 1870–71. The greatly broken and disturbed character of the supposed upper series, the obscure stratification of much of the underlying group, and the frequent occurrence of intrusive masses combine to make the determination difficult. There can, however, be no question that most of the calcareous and siliceous strata are more recent than the coarse granitoid rocks with which they are associated. With one possible exception no instances of direct superposition of the Coldbrook rocks on the Laurentian have been observed; but the Coastal rocks are found upon the Coldbrook rocks as well as upon the Upper Laurentian, so there is no reasonable doubt as to the true succession. Contacts of the Coastal group with the Coldbrook group are found in the county of St. John, and especially along the line of the St. Martins and Upham Railway, between Upham and Quaco, and on the lower Quaco road on either side of Bloomsbury Mountain. In passing from one to the other there is often an abrupt change of dip, the beds of the higher series dipping at a lower angle than those upon which they rest, while along the same line of contact it is not uncommon to find masses of coarse breccia conglomerate, in which the fragments are largely the petrosilex derived from the inferior group. It is, however, questioned whether the unconformity is sufficient to prove the fact of any considerable lapse of time. The age and equivalency of the Kingston group, as well as of the Mascarene Peninsula, are somewhat uncertain, owing to the difficulty of obtaining stratigraphical evidence and to the close resemblance which many of them bear on the one hand to the rocks of the Huronian and on the other to those of the Silurian.

Bailey,[21] in 1881, in summarizing the work of the survey in New Brunswick, concludes that there are a Laurentian and a Huronian, as in other parts of Canada. These are below the Primordial by a marked unconformity. These rocks east of St. John occupy irregular troughs in the pre-Silurian rocks, resting sometimes upon one and sometimes upon another of the subdivisions of the latter, crossing their strike obliquely and having coarse basal conglomerates. There is almost perfect lithological likeness between the great mass of rocks referred to the Laurentian, including coarse and fine grained gneisses, quartzites, graphitic and serpentinous greenstones, and dolomites, and the Laurentian of other parts of Canada, and particularly the Hastings series of Vennor. This series is capped by the great volcanic series of the Huronian. These pre-Silurian rocks are confined wholly to the region of the southern metamorphic hills, nothing of equivalent age having yet been identified in the central and northern portions of the province. In the rocks referred to the Huronian are two well-marked divisions, the lower or Coldbrook group and the upper or Coastal group, between which there is not infrequently evidence of at least a partial unconformity. The pre-Silurian rocks are of vast thickness; their divisions were deposited under markedly different conditions; there are unconformities between these divisions. These facts show that these rocks are at least as old as the Huronian and portions of the Laurentian system. Above the Upper Silurian rocks are found felsite porphyries and peculiar orthophyres at Passamaquoddy Bay and at Eastport and Pembroke, Me. On St. John River, associated with the fossiliferous rocks are amygdaloidal and ash rocks which are indistinguishable lithologically from the Huronian formation, to which all of these rocks have previously been referred.

Bailey,[22] in 1885, finds the granites of southern and Central New Brunswick to be of intrusive character and to cut rocks as late in age as the Carboniferous. As evidence of this are cited the abrupt transitions from the massive granite to the associated schists; the widely different characters of the invaded beds; the fact that foliation and crystallization are most marked in the vicinity of the granite and decrease with increase of distance from it; the outlines of the granite are irregular and are in some places parallel with, in other places oblique to, and in still others at right angles to, the foliation of the rocks cut; detached masses or bosses of granite border main granitic areas; granite veins like those of the main mass of granite penetrate the schists in all directions adjacent to the granite masses; large detached blocks of schists and gneiss, usually angular, are frequently contained in the granite, sometimes being so abundant as to produce the appearance of a coarse breccia. As to the age of these granites, no veins are found penetrating later strata than the Upper Silurian, but all conglomerates older than the Lower Carboniferous are destitute of granite pebbles, while the later formations abound in them, which appears to indicate that the granites are Devonian.

Ells,[23] in 1886, finds in Albert County pre-Cambrian rocks which include quartzite, felsite, gneiss, syenite, and granite. The crystalline limestone rests generally upon the flanks of the schistose series. These rocks are an eastern extension of the pre-Cambrian of western New Brunswick.

Bailey,[24] in 1890, says that the evidences of unconformity between the Primordial and the Archean are clear, varied, and widely distributed. It is equally evident that the Archean consists of two groups of sediments, which in many features resemble the Laurentian and Huronian systems of Canada; but there are equally striking differences between the supposed Laurentian rocks of St. John and those of Canada. This is especially marked by the greater proportional amount in the former of distinctly stratified rocks, such as slates and quartzites, and the absence of coarsely crystalline deposits. As regards the Huronian rocks, the greater part were referred to as felstones, clay stones, porphyries, and petrosilex before the introduction of the present methods of petrographical research, and their names in some instances are probably misapplied. The relations of the Laurentian and Huronian systems are not well understood. While the author does not doubt that the clastic and schistose rocks referred to the Huronian are more recent than the granitoid gneissic and crystalline limestones regarded as Laurentian, a contrary view has been taken by others.

MATTHEW,[25] in 1890, states that in the Upper Laurentian of New Brunswick fossils occur at three horizons. The oldest of these is in a quartzite in the lower half of the system. This contains hexactinellid sponges, allied to the genus *Cyathospongia*. The second horizon is in the upper limestone. It contains calcareous coral-like structures which bear a resemblance to *Stromatopora rugosa*. The third horizon is that of the graphite beds, in which occur great numbers of sponge spicules, arranged in parallel sets, one set crossing the other at an acute angle. The type of sponge is apparently monactinellid. *Eozoon* also occurs in the Laurentian. Between the Upper Laurentian system and the basal Cambrian occurs a third system of rocks, the Coldbrook and Coastal, which has given conglomerates to the Cambrian and has a great thickness.

MATTHEW,[26] in 1894, describes the pre-Cambrian area near St. John, New Brunswick. The earliest series, or Laurentian, consists chiefly of granitic and gneissoid rocks, limestones, and quartzite, the two latter being confined to the upper beds. The strata lie steeply inclined in a succession of ridges and folds striking in a general northeast-southwest direction. Overlying this more crystalline series, generally at a lower dip, are fine-grained flinty rocks, interbedded with various schists, porphyries, ash rocks, and sandstones, and with great masses and dikes of trap. These have been called Huronian.

The old part of the Laurentian consists of gneisses proper, accompanied by hornblende schists and mica schists, which in thin section show no trace of igneous origin, and of limestone and quartzite. Associated with the less crystalline limestones are beds of fine-grained black rock, which has generally been called argillite. Much of the Lower Laurentian series consists of granite, diorite, and gabbro, which are igneous rocks. The granite intrudes both the gabbro and the sedimentary series, as is shown by contact effects and by veins and pegmatite masses adjacent to the granite in the sedimentary series. As to the age of this intrusion, it may be as late as Devonian, but as the granite is cut by innumerable dikes which also cut the Huronian and the Paleozoic, it is very likely that the intrusion is pre-Huronian. The great unconformity in the district is between the Laurentian and the Huronian, not between the Huronian and the Cambrian.

MATTHEW,[27] in 1895, gives the following pre-Cambrian succession near St. John, New Brunswick:

A. Laurentian:
1. Portland group, including division 2, with probably parts of division 1 in other localities than St. John.
2. Intrusive granite and quartz diorite; perhaps later than the position here assigned to it.

B. Huronian:
3. Coldbrook group or division 3, of volcanic rocks.
4. Coastal group or division 4, of volcanic and sedimentary rocks, in its upper part probably equivalent to the next group.
5. Etcheminian or Basal series, of sedimentary rocks, underlying the St. John group.
6. Kingston group or division 5, of metamorphosed volcanics. Of very uncertain relations; may be post-Cambrian.

The Huronian in southern New Brunswick is in large part made up of surface volcanic rocks. The lower part, or Coldbrook group, is almost exclusively volcanic; the upper part, or Etcheminian, is clastic, while the intermediate Coastal contains both volcanic and sedimentary members. The effusive rocks include lavas, breccias, and tuffs, and with them may be placed a holocrystalline soda granite which is probably either an intrusion or a very thick surface flow.

The Etcheminian series rests unconformably upon the Coldbrook series and unconformably below the St. John group, which is for this district placed at the base of the Cambrian. The igneous rocks comprise effusives, including quartz porphyry, felsite porphyry, diabase, and feldspar porphyrites, and dike rocks, which include diorite porphyrite, diabase, and augite porphyrite. Each of these is described in detail.

MATTHEW,[28] in 1899, describes a Paleozoic terrane beneath the Cambrian in St. John and Kings counties, New Brunswick, on Cape Breton, and near Smith Sound, Newfoundland. This terrane is unconformably below Cambrian strata bearing *Paradoxides* and *Protolenus* fauna, and is given the name Etcheminian. The faunal features as distinguished from the Cambrian are the great preponderance of tube worms, absence or rarity of trilobites, minuteness of the gasteropods except Patellidæ, minuteness of the brachiopods, and minuteness of the crustaceans.

WALCOTT,[29] in 1899, states that in New Brunswick certain rocks placed by Matthew below the Middle Cambrian contain fossils which may be pre-Cambrian.

He also believes the Etcheminian terrane of New Brunswick and Newfoundland, called pre-Cambrian by Matthew, to be of Lower Cambrian age. His evidence is:

1. That the *Olenellus* fauna in Newfoundland occurs 420 feet beneath the *Paradoxides* fauna, in the heart of the Lower Cambrian "Etcheminian."

2. That fragments of the fauna are found 460 to 480 feet below the *Protolenus* fauna in the "Etcheminian" of the Hanford Brook section of New Brunswick.

3. That in the undisturbed, unbroken Highland Range section of Nevada the *Olenellus* fauna is 4,450 feet below the Upper Cambrian fauna, and that the *Olenoides* (*Dorypyge* fauna of Matthew) is 3,000 feet below the horizon of the Upper Cambrian fauna and 1,450 feet above the horizon of the *Olenellus gilberti* fauna.

4. That in the southern Appalachians the *Olenellus* fauna occurs more than 7,000 feet below the highest Cambrian fauna known in that region, and fully 2,000 feet below a typical *Olenoides* fauna.

MATTHEW,[30] in 1900, makes rejoinder to Walcott's discussion of the age of the Etcheminian terrane. He argues that Walcott depends chiefly upon the presence of *Coleoloides typicalis* as showing the presence of the *Olenellus* fauna; that this form is not always distinguishable from *Hyolithellus micans*, a problematical fossil probably of the tube worms, which, with the brachiopods, is the most striking of the fossils of the lower (Etcheminian) terrane. Moreover, the particular form of *Olenellus* which Walcott has found is *Olenellus bröggeri*, rather than *Olenellus thompsoni*, the original *Olenellus*. *Olenellus thompsoni* is supposed to occur above *Olenellus bröggeri*, yet the *Protolenus* and *Paradoxides* faunas follow in regular succession to the fauna of the *Olenellus bröggeri*. The question is asked: Where is the fauna of *Olenellus thompsoni?* Its absence is supposedly taken as evidence of the presence of the unconformity held by Matthew.

MATTHEW,[31] in 1902, refers the Etcheminian and underlying volcanics (correlated with the Coldbrook of New Brunswick) of Cape Breton to the Cambrian, and implies that the same reference should be made of the New Brunswick Etcheminian and Coldbrook.

ELLS,[32] in 1904, gives a preliminary account of new work on the geology of Charlotte County, New Brunswick. The series of slates, schists, eruptives, and crystalline limestones which occur on Letite and Frye Island, and thence southwestward through the group of islands including Deer, Campobello, Grand Manan, and many other smaller ones, which are a part of a somewhat extensive chain trending in this direction, are found to contain Silurian and Devonian fossils. Their general aspect is like that of many of the rocks east of St. John, included in the Kingston group, these having been regarded as of Huronian age, since they, in part at least, underlie rocks which hold primordial fossils.

ELLS,[33] in 1905, reports on the geology of Charlotte County, New Brunswick, particularly the rocks of Grand Manan Island, and of portions of the shore of the Bay of Fundy between Beaver Harbor and Point Lepreau, where, at different places, through the agency of intrusives, the ordinary sedimentary rocks of Silurian and Devonian age had become altered to the condition of schists of pre-Cambrian aspect.

ELLS,[34] in 1906, summarizes some of the problems in New Brunswick geology.

NORTHERN AND CENTRAL NEW BRUNSWICK.

ROBB,[35] in 1870, gives a report on the geology of central New Brunswick. The crystalline rocks include (1) a band of metamorphic rocks immediately underlying the Carboniferous series and extending to the southeastern boundary of the great granite area, (2) the central granite area, and (3) a band of noncalcareous metamorphic slate and quartzite lying immediately northwest of the granite area. The southern slate band extends from Magaguadavic Lake to the southwest Miramichi, its breadth varying from 9½ miles on St. John River to 17 miles on the Miramichi. The rocks consist of argillaceous and micaceous clay slates, with interposed bands of crystalline, quartzose, micaceous, and feldspathic rocks resembling sandstone. They are doubtless altered sediments. In one place apparently in this series are fossils, probably of Upper Silurian or Devonian age. The central granite occupies a considerable area to the northwest of the slates. The line between the slates and the granite is somewhat arbitrary, for the slate and quartzite band includes three very considerable, with some smaller, bands of granite. The various feldspathic rocks of the region seem to merge into one another. This is true not only of the granite and gneiss but even of the foliated semicrystalline slates and quartzites. Occasionally fragments of gneiss of all shapes and sizes are found embedded or incorporated in the granite, and vice versa; but no appearance of granite veins cutting the laminated rocks is noted. The slates, mica schists, and quartzites of the northern slate belt locally assume a crystalline aspect. Bands of crystalline rocks resembling granite, syenite, and diorite are intercalated in the manner of conformable or interbedded masses. At one place is found a slate conglomerate, which is believed to occupy a depression in the older rocks.

ROBB,[36] in 1872, gives some additional facts in continuation of his studies. The central granite area is divided into two granitic bands. Much of the granite area is of a gneissoid character. Where the change from granite to slate occurs the granite near the line of contact is often of a red variety and rather fine grained, gradually passing into the ordinary color and texture in receding from the line. All attempts to elucidate the structural relations of the granite have proved futile. In the slate band northwest of the granite are conformable dikes of diorite, syenite, and other feldspathic rocks. Immediately at the junction of the granite with this series is a band of pure crystalline limestone.

Ells,[37] in 1881, reports on the geology of northern New Brunswick. The pre-Cambrian rocks are believed to underlie unconformably the Cambro-Silurian. The typical rock is a grayish feldspathic gneiss, frequently containing hornblende. The rocks referred to the pre-Cambrian include granites, felsites, gneisses, and schists. Granites, diorites, dolerites, and felsites are found. A portion of these are mingled with the pre-Cambrian, but others, and especially the basic eruptives, are found in the slates and other rocks belonging to the fossiliferous series. At the contact of the granites with the slates in places the latter become crystalline and contain crystals of staurolite.

Ells,[38] in 1883, finds crystalline mica schists, quartzites, etc., which are provisionally referred to the pre-Cambrian system. At two places they underlie conformably the Cambro-Silurian series.

Bailey,[39] in 1885, in a report on York and Carleton counties in central New Brunswick, finds no rocks which are regarded as pre-Cambrian; but granites, syenites, basalts, and diabases occur which are regarded as intrusive. Interstratified with the Lower Carboniferous are beds of volcanic or semivolcanic origin. The granite is filled with embedded fragments of other rocks, so that in places it has the appearance of a conglomerate. Beyond question they come from the schistose and micaceous rocks which border the granite, as is shown by their identity in character with these rocks. Also the lines of contact show the intrusive character of the granite.

Bailey,[40] in 1886, in continuing his work in central New Brunswick, finds highly crystalline strata, including gneisses, syenites, and felsites, which are referred to the pre-Cambrian. They are thought to be a continuation of those described by Ells. In this pre-Cambrian are included without doubt very considerable masses of igneous rocks.

Bailey and McInnes,[41] in 1887, in continuing work on central New Brunswick, find felsites, quartzites, and mica schists, which are referred to the pre-Cambrian. Only the boundaries of the rocks are mapped, no attempt being made to work out the structure. These rocks are cut by granites, which are found in two areas. These granites are the same in character as those which have been previously described as of probable Devonian age.

Bailey,[42] in 1903, makes geological observations in northern New Brunswick, in the region about the headwaters of Tobique and Nipisiguit rivers. In previous mapping a large part of the area was called pre-Cambrian. The work of the summer seems to show that the rocks may be of later, perhaps Silurian, age. No fossils are found.

SUMMARY OF PRESENT KNOWLEDGE.

SOUTHERN NEW BRUNSWICK.

Dr. G. F. Matthew has kindly prepared this summary of the pre-Cambrian succession of southern New Brunswick:

From the base up the series are:

1. An undetermined mass of feldspathic and chloritic and hornblende schists, with very little limestone. Intrusive into division 2.

2. "Upper series of the Laurentian," with heavy masses of limestones, quartzites, etc. This has been termed Grenvillian.

These two groups are injected with masses of quartz diorite, protogene, syenites, gabbros, and diorites, many of the latter altered to serpentine. These intrusions are more ancient than any succeeding clastics, as they nowhere cut the latter.

Unconformity.

3. A great series consisting in the lower part chiefly of chloritic and feldspathic schists and in the upper of various argillites, dark-gray slates, graywacke, and bedded diorites. (The hydro-mica schists, feldspathic schists, and argillites of the eastern part of St. John County appear to be the lower part of the series.) This series has been called Huronian in the geological reports; it is probably Murray's Intermediate system of Newfoundland. It extends along the north side of the Long Reach of St. John River, and southwestward into the islands of Passamaquoddy Bay, with prevailing southwesterly dips.

4. The Kingston series or terrane. This is entirely an effusive series, made up of diorites and hornblendic, micaceous, and feldspathic schists, the last especially toward the top. It occupies the peninsula between the Long Reach and Kennebecasis River, extending northeast and southwest from there. As it separates from No. 3 going westward, it is supposed to be an unconformable, later series.

The Coldbrook and Etcheminian terranes being regarded by me as Cambrian, I know of no later pre-Cambrian terrane or formation in this area than the Kingston series.

The Coldbrook series is closely related to the Etcheminian, always underlies it, and is not altered so that its rocks become crystalline, further than they may have been as volcanic rocks. In Cape Breton a volcanic series, similar in aspect, and lying between Etcheminian and Grenvillian, contains unaltered argillites or clay slates with fossils of Cambrian type (*Lingulella*, *Lingulepis*, *Obolus*, *Acrothyra*, etc.). We therefore can not separate the Coldbrook from the Cambrian.

I question whether the so-called Coastal series of previous classifications can be regarded as an independent series, or while a portion of it may be such, a great deal should be referred to other horizons. The rarity of fossils, or obscured relations to the Paleozoic sediments, has been the reason for referring to this group much that is probably Paleozoic, especially in the view that the Coldbrook and Etcheminian are both Paleozoic.

Correlation.[a]—Divisions 3 and 4, following usage in other districts, are provisionally correlated with the Algonkian. The rocks of division 1 are, according to Matthew, mainly intrusive into the Grenville of division 2. The correlation of the Grenville of this district presents the same problems as that of the original Laurentian and Hastings districts, where it may be noted there is still doubt as to

[a] By the authors.

what extent the Grenville is itself divisible into two series, its relations to the igneous rocks and gneisses, and to what extent it is to be correlated with the Algonkian or Huronian.

The difficulty of the geology of this region is shown by the manner in which these groups have been shifted from one place to another. In the days of the earlier work none of them were regarded as pre-Cambrian, and a portion was given as high a place as the Devonian. The Kingston group in 1865 was called "Upper Silurian" and was regarded as overlying the St. John; in 1872 it was called "Upper Huronian;" in 1876 was again placed as "Silurian;" in 1879 was again placed with the "Upper Huronian;" and now is assigned to the Silurian. The "Coastal," first placed in the fossiliferous series, in 1872 was placed in the "Middle Huronian series;" in 1878 was doubtfully referred to the "Laurentian," and in 1879 was again returned to "Middle Huronian." The Coldbrook group has been reckoned as Huronian since 1865, but on the discovery of fossils in similar rocks between the Etcheminian and "Grenvillian" rocks of Cape Breton, Matthew has concluded that the Coldbrook could not be separated from the Cambrian.

NORTHERN AND CENTRAL NEW BRUNSWICK.

In central New Brunswick are numerous areas of granites, gneisses, and schists, associated with other rocks which are plainly of sedimentary origin, including mica schists, quartzites, and slate. Felsites are also found. Granite, syenite, and diorite in certain places are intercalated with the sedimentary rocks, and in other places cut them. From the descriptions it appears clear that there are Algonkian rocks in this area. Whether crystalline rocks older than the Algonkian also exist can not be decided from the information available.

There is little difficulty in separating the intrusives from the fossiliferous rocks, but on account of the more crystalline character of the older series and its likeness in mineralogical composition to certain of the subsequent intrusives, and further, on account of the intimate mingling which occurs between these two classes of rocks, it is difficult to make the separations with the same degree of sharpness. This difficulty is not improbably further increased by the presence of intrusives earlier than those which cut the Cambro-Silurian rocks.

SECTION 2. NOVA SCOTIA AND CAPE BRETON.

SUMMARY OF LITERATURE.

Jackson and Alger,[43] in 1832, in remarks on the mineralogy and geology of Nova Scotia, find the granites to protrude through the clay slates. They are, however, regarded as older than the slates, the latter having been deposited on them in a horizontal position. This granite is the only Primitive rock of Nova Scotia. The line of junction between the slate and granite was not observed. The slates are cut by numerous dikes believed to be of igneous origin.

BROWN,[44] in 1843, places the whole northern part of Cape Breton in the Primary rocks. Cape North is composed of mica slate, gneiss, and granitic rocks apparently interstratified, with an east-west strike and upturned nearly on edge. Igneous rocks occupy a large part of the island. These protrude through the limestones and graywackes which are associated with the coal measures.

DAWSON (Sir WILLIAM),[45] in 1850, divides the metamorphic rocks of eastern Nova Scotia into two groups, one along the Atlantic coast and vicinity, and another belt to the west, parallel to the first. The coast group consists of quartzites, mica slates, and clay slates, which are cut by granites, and it is therefore called the granitic group of metamorphics. The second group, the slates and quartzites, include micaceous and talcose schists, while the intrusive rocks are syenites, and the group is therefore called the syenitic group. The syenitic group rests unconformably below the carboniferous rocks, the latter containing fragments from the former. These are seen at numerous points. Both of these groups of rocks are regarded as belonging to the fossiliferous series, the syenitic group being Silurian. The granitic group is probably older than the syenitic, and therefore also Silurian or pre-Silurian, but the actual superposition of the beds of the two groups was not observed.

DAWSON (Sir WILLIAM),[46] in 1855 and 1868, places in the Upper Silurian large areas in the northern and eastern parts of Cape Breton, as well as other smaller areas, and large areas in northern Nova Scotia and in southern Nova Scotia northwest of the gold-bearing series. The rocks have been subjected to great disturbances and are much complicated in structure. They include many varieties—syenite, porphyry, greenstone slates, quartzites, conglomerates, and sandstones. Large areas of granitic rocks are also found associated with the metamorphic series referred to the Upper Silurian.

The Lower Silurian covers a very large area along the Atlantic coast of Nova Scotia, known as the gold-bearing series. This area has afforded no fossils, but appears to be a continuation of Jukes's older slate series of Newfoundland, which contains *Paradoxides*. Among the metamorphic rocks of this region are gneiss, mica slate, quartz rock or quartzite, and clay slate. The gneiss is unquestionably the product of metamorphism due to the baking of sedimentary rocks by heat and water, while the quartzite consists of grains of flinty sand fused together. The preponderant rocks are thick bands of slate and quartzite having a general northeast-southwest strike and highly inclined. Whether the mica schists and gneiss of Cape Canso and Queens and Shelburne counties and the chloritic beds of Yarmouth are to be regarded as more metamorphosed members of the Lower Silurian slates or are still older deposits remains uncertain. Granite is found in several places in the region in large masses projecting through the slates and quartzites, and adjacent to the granite these rocks are replaced by gneiss and mica slate or other more highly metamorphosed rocks. The metamorphism of the rocks must have occurred prior to the Carboniferous period, and there is no doubt that the granite rocks have been the agent in effecting it, if they are not themselves portions of the stratified beds completely molten and forced up by pressure against and into the fissures of the neighboring unmelted rocks. Whatever view is taken as to the age of the granitic rocks, it is certain that they are strictly Hypogene—that is, they belong to deep-seated foci of subterranean heat and are not superficial products of volcanic action, but were probably at one time deeply buried.

CAMPBELL,[47] in 1863, divides the gold-bearing slates into a lower or quartzite group and an upper or clay slate group.

HIND,[48] in 1869, finds in the Waverly beds of the gold-bearing rocks obscure fossils, which are regarded as evidence that these rocks probably lie near the base of the Lower Silurian, perhaps being the equivalent of the Potsdam or lower part of the Calciferous.

HIND,[9] in 1870, describes the series of gneissic and granite rocks which are said to extend as an interrupted axis from the Gut of Canso to the Tusket Islands. These have heretofore been regarded as eruptives, because dikes of granite are frequently found in the quartzites which are supposed to be Silurian, and also fragments of quartzites and slates are embedded in the granites near the contacts. It is, however, concluded that the granite is a sedimentary deposit resting unconformably below the slates and quartzites. The chief proof of the aqueous origin of the granitic rocks is the abundance of water-worn pebbles and bowlders, not only near the junction of the quartzites but remote from these rocks. These pebbles are symmetrically arranged, showing the dip of the gneiss. They are often smooth and rounded, but masses of schists are also contained which do not present rounded edges. The granites or gneisses are seen to break through the gold-bearing series in many places, but they are regarded as brought up by faulting; but in certain places on the line of the Halifax and Windsor Railway the gneisses were in a plastic state when the uplift took place, for veins are found squeezed into the cracks and interspaces of the thinly bedded gold-bearing rocks.

The sequence of formations is: Upper Silurian, Lower Silurian, Cambrian or Huronian, and Laurentian. The Upper Silurian is a series of argillites estimated at 9,000 feet thick. The Lower Silurian consists of micaceous, schistose, and corrugated black slates, and are estimated to have a thickness of 12,000 to 15,000 feet. The gold-bearing Silurian rocks are seen to rest unconformably on a gneissoid series between Stillwater and Uniacke station on the Halifax and Windsor Railway, and near the village of Sherbrooke, in Guysboro County. This series of Huronian rocks is composed of beds of gneiss, interstratified with micaceous schists, schist conglomerate, beds of true quartzite, and grits. The gneiss is sometimes porphyritic, and the upper beds are almost always conglomeratic, holding pebbles and masses of schists, grits, and conglomerates, which are found in this series. This older series rests unconformably upon the Laurentian. The contacts are visible on the Halifax and Windsor Railway, near New Stillwater and Mount Uniacke stations. The gold-bearing Silurian strata are also found to repose unconformably upon the Laurentian. This contact is also observed near Mount Uniacke station.

Silliman,[50] in 1864, finds that the gold-bearing rocks of Nova Scotia extend along the Atlantic coast for 250 miles, from Cape Sable to Cape Canso. These rocks are hard, slaty ones, which are sometimes micaceous schists, and occasionally granitic. When stratified they are always found standing at a high angle, sometimes almost vertical, and in the main with an east-west course. The zone of metamorphic rocks varies in width from 6 to 8 miles at its eastern extremity to 40 or 50 at its widest part, the area covered being about 6,000 square miles. While no fossil evidence has been found in any of these slates, opinion seems to favor the belief that they belong to the Silurian age, but as yet no place has been found where the rocks next higher in the geological column may be seen resting upon them. The most noticeable rock of the gold region is a dark-gray massive rock, which resembles a trap, but which is really a granular quartzite. It has three well-defined planes of cleavage, by which it breaks into very irregularly shaped masses. This rock is of enormous thickness, and is undoubtedly the fundamental or basement rock of the region.

Selwyn,[51] in 1872, in studying the gold-bearing slates, believes that they belong to the Primordial-Silurian epoch. As evidence of this is given the discovery, in the slates of Ovens Bluffs, of numerous specimens of the genus *Eophyton*.

The granite impresses this author as of strictly indigenous character, and neither a granitoid gneissic series of Laurentian age nor an intrusive mass. The line of contact with the Silurian and Devonian leaves no doubt of its posterior origin, but whether intrusive or metamorphic in situ is perhaps uncertain.

Robb,[52] in 1876, finds that a massive syenite and associated crystalline rocks have a rather widespread distribution in Cape Breton. At some points the Carboniferous rocks are brought into contact with the syenite, but at a few points there are interposed metamorphic calcites, argillites, and quartzites, associated with dolomites and other magnesian rocks, which are in a vertical or highly inclined position and evidently belong to a pre-Carboniferous altered sedimentary series. The junction of the pre-Carboniferous limestones with the syenite is approximately parallel to the mountain range, but is locally irregular, and in some instances the limestones seem to fill depressions in the syenite. The Lower Carboniferous rocks in places rest directly upon the syenite, filling the hollows in it, and have basal conglomerates, the débris of which is derived from the underlying syenite, limestone, and quartzite.

FLETCHER,[53] in 1877, finds in Cape Breton, below the Lower Silurian rocks (afterward found to carry *Paradoxides*), first, a set of syenitic, gneissoid, and felsitic rocks; and second, the George River limestone series, consisting of crystalline limestones and dolomites, interstratified with felsite, syenite, diorite, mica schist, quartzite, and quartzose conglomerate; both of which are referred to the Laurentian, although the latter may be Huronian. The Lower Silurian shales lie nearly horizontally upon the syenites and felsites, without any appearance of alteration and without being intruded by the felsites or syenites. The crystalline limestone series is in close affinity with the feldspathic group of rocks, but is distinct, as is shown by the occurrence of pebbles of syenite and felsite in the quartzose conglomerate of Murphy Brook.

FLETCHER,[54] in 1878, continues his study of the pre-Cambrian of Cape Breton and northern Nova Scotia. The George River limestone is bounded on both sides by coarse syenitic and granitic rocks and is in apparent unconformity with them.

DAWSON (Sir WILLIAM),[55] in 1878, places the rocks of the Boisdale Hills in Cape Breton as older than the Lower Silurian, and it is not impossible that rocks of the same age may occur in the vicinity of the Cambrian beds at Mira. Also the chloritic rocks of Yarmouth may conjecturally be placed with the Huronian. With the exception of the rocks of St. Anns Mountain, of the island of St. Paul, and some parts of northern Cape Breton, no rocks are found which are regarded as lithologically equivalent to the Laurentian of Canada.

FLETCHER,[56] in 1879, describes the pre-Primordial rocks as occupying two large areas, one constituting the Mira Hills, while the other is a belt of variable width along the shore of the Atlantic. There are two basins of metamorphic rocks running parallel to the felsite series; one of these abounds in Primordial fossils, and the second is probably of Devonian age. The latter contains masses of granitoid and trappean rocks.

FLETCHER,[57] in 1881, in continuing his studies in northern Nova Scotia, again divides the pre-Cambrian rocks into two groups. In the first or felsitic group quartzites are also found intimately intermingled. The George River limestone series is considered as an unconformable overlying group of pre-Cambrian age. The limestones in every case cap the felsites, with which, however, they often seem to blend near the contacts as if by a common metamorphism. As evidence of this unconformity are cited the occurrences of limestone in a higher position than the syenites and felsites; the irregular line of contact by which the syenite passes under the limestone; and the absence of veins and dikes of syenite in the limestone. The rocks are sometimes intricately mingled, as at Dallas Brook, where layered felsite, limestone, and slate are met with, while on the top of the hill limestone occurs, and farther back syenite, displaying a coarse admixture of finely foliated gneiss. In some localities the syenite begins abruptly, as if cutting veinlike across the strike of the gneiss; in others the change from syenite to gneiss is gradual. The gneiss is associated with large masses of white quartzite. Metamorphic rocks are described which are referred to the Devonian, but the evidence is so slight that it is concluded that all of these strata may belong to an older period. Between them and the pre-Cambrian series there is a marked unconformity, and also one of less importance between them and the Carboniferous.

FLETCHER,[58] in 1885, finds that in northern Cape Breton the syenitic, gneissoid, and other feldspathic rocks of the Lower pre-Cambrian group are intimately mingled on Margaree River with foliated rocks. At Coinneach Brook, where the syenite comes in contact with the contorted mica schist, the latter is seen to underlie the syenite. Higher up the syenite again appears and contains a layer 5 feet thick of mica schist, which is, as it were, intruded among the syenites. Red granite overlies unconformably the strata of the George River limestone group at Fionnar Brook.

GILPIN,[59] in 1886, describes the pre-Cambrian rocks of Cape Breton as including a felsite series and a crystalline limestone series, the latter unconformably overlying the former; both are referred to the Laurentian. With the felsites and interstratified porphyries are also syenitic and gneissic rocks; while the crystalline George River limestone also contains, interstratified with the limestones, syenites, diorites, mica schists, quartzites, and quartzose conglomerates. The limestone area is limited in extent as compared with the felsite group.

FLETCHER,[60] in 1887, further describes the pre-Cambrian rocks of a part of northern Nova Scotia. The crystalline rocks here found resemble none known as Cambrian in other parts of Nova Scotia, and are strikingly like those beneath the Cambrian in Cape Breton. Although they are certainly known to rest unconformably below the Cambro-Silurian strata, a part or all of these rocks may be Cambrian or even Cambro-Silurian. Similar gneisses and schists in southern New Brunswick have been included by Bailey in his Cambro-Silurian series. Volcanic rocks, both basic and acidic, and varying in age from pre-Cambrian to Devonian, or even Carboniferous, are abundant.

FARIBAULT,[61] in 1887, reports on the gold-bearing area of southern Nova Scotia. These rocks occupy 6,000 or 7,000 square miles. They are divided into a granitic division and a lower Cambrian division. The lower Cambrian rocks include quartzites, clay slates, and conglomerates, and are estimated to have a thickness of 15,000 feet. These rocks, always greatly altered, are much more so when cut by masses of granite, and over considerable districts have been rendered thoroughly crystalline, the quartzites passing into fine gneissic rocks, and the mica slates into mica schists. Faribault, following Campbell, divides them into a lower or quartzite group, 11,000 feet thick, and an upper or graphitic and ferruginous slate group, about 4,000 feet thick. The first of these, while in the main quartzite, is interstratified with numerous bands of slates and one or two of conglomerate. The Cambrian rocks are greatly disturbed from their original horizontality, being folded into a series of sharp parallel undulations. In the more altered portions the planes of bedding are not easily distinguished from those of slaty cleavage, the latter often being more distinct. The rocks are referred to the Cambrian upon the evidence of a single fossil, *Eophyton*. The group is analogous in some respects to Lawson's Lake of the Woods series. The granites cut the Cambrian rocks at many places, and at times are associated with gneisses. At the edge of large masses the granite frequently passes into a foliated schistose rock, losing its crystalline texture, and itself passing insensibly into the altered sedimentary rocks.

DAWSON (Sir WILLIAM),[62] in 1888, places the isolated rocks of St. Anns Mountain in the lower Laurentian, and regards it as probable that rocks of this kind exist in the northern extremity of the island. In Nova Scotia proper no true Laurentian is recognized, the rocks here referred by other observers being intrusive granite masses of much later date associated with altered rocks.

BAILEY,[63] in 1895, gives a preliminary report upon southwestern Nova Scotia. The oldest rocks here found are those of the Cambrian system, in which there is the following succession from the base upward:

1. Quartzite division:
   - (*a*) Heavily bedded blue quartzites, with slightly plumbaginous partings, alternating with numerous but much thinner beds of gray argillite. In metamorphic areas the quartzites become more micaceous, assuming the aspect of fine-grained gneisses, while the finer beds become glistening mica schists.
   - (*b*) Greenish-gray sandstones or quartzites, less massive than in (*a*), and alternating with slates which are arenaceous below but become gradually more argillaceous above.

2. Slate division:
   - (*a*) Greenish-gray slates, becoming bluish or light gray, and passing into purple slates, or becoming clouded or zoned with shades of green, purple, blue, buff, or pale yellow, often producing a conspicuous ribboning of the beds. The occurrence of light yellowish-green seams is a characteristic feature of the purple slates.
   - (*b*) Bluish-gray and blue slates, with lighter gray seams or bands, and including in places an upper zone of purple slates.
   - (*c*) Black, with some blue or gray, slates, often highly pyritiferous. In metamorphic regions the green slates are represented by chloritic and hornblendic schists (or locally by conglomerates with a micaceous or hornblendic base); the slaty beds, by micaceous, garnetiferous, and andalusitic schists.

Above the Cambrian rocks are those belonging to the Devonian system. There are several important areas of granite—those of South Mountains, Blue Mountains, Tusket Wedge, the Barrington area, Kelvin area, and Port Mouton area. These are intrusive within the Cambrian, and in places they clearly penetrate and alter the fossiliferous Lower Oriskany and Silurian rocks.

Bailey,[64] in 1898, reports on the geology of southwestern Nova Scotia. Cambrian rocks devoid of fossils occupy a large part of the area. The succession is as follows, in ascending order:

1. Quartzite division:
   - (*a*) Heavily bedded bluish quartzites, alternating with much thinner beds of argillite.
   - (*b*) Greenish-gray sandstones or quartzites, somewhat chloritic and less massive than in (*a*), and alternating with slates which are arenaceous below but become progressively more argillaceous above.
2. Banded argillite division:
   - (*a*) Greenish-gray slates, becoming bluish or light gray, and passing upward into—
   - (*b*) Purple slates, marked in the lower beds by pale, yellowish-green seams, with faint bedding lines, which are wanting in the higher beds.
   - (*c*) Bluish-gray and gray slates, often with cloudings of green, purple, lilac, buff, or yellow, in places exhibiting a conspicuous banding or ribboning of the beds.
3. Black slate division:
   Black slates, with some blue or gray, often studded with cubes of pyrites, and very rusty weathering.

Faribault,[65] in 1899–1905, estimates the area of gold-bearing series at 8,500 square miles, including 3,500 square miles of intrusive granite, leaving 5,000 square miles of gold measures proper. Intrusion of granite occurred at the close of the Silurian, probably Oriskany, and was accompanied and followed by disturbances, faults, and much local metamorphism of the stratified rocks. It occurred after the folding of the sediments and the deposition of the auriferous quartz veins. No well-defined fossils have so far been found, but the sediments are generally ascribed to the Lower Cambrian on account of their analogy with the Harlech grit and *Lingula* flag series of North Wales, the auriferous Cambrian of Quebec, and Murray's

Intermediate series of Newfoundland. The gold-bearing series is divided into two well-defined and distinct divisions—a lower or quartzite group, now designated by the name Goldenville division, and an upper or slate group, called the Halifax division. A detailed structural mapping of the greater part of the area covered by these rocks on a scale of 1 mile to the inch gives a thickness of about 3 miles to the lower division and 2 miles to the upper; total thickness, more than 5 miles.

MATTHEW,[66] in 1899, discusses the Etcheminian fauna of Cape Breton and places it beneath the Cambrian of that locality.

MATTHEW,[67] in 1902, finds the Etcheminian terrane of Cape Breton, previously assigned to the pre-Cambrian, to contain Cambrian fauna. The volcanics, into which the series grades below (correlated with the Coldbrook of New Brunswick), also contain slates with Cambrian fossils, and hence this series of volcanics with the Etcheminian is now classed with the Cambrian.

ELLS,[68] in 1902, summarizes the progress of geological investigation in Nova Scotia.

FLETCHER,[69] in 1903 and 1904, gives a brief preliminary account of surveys and explorations in Nova Scotia.

WOODMAN,[70] in 1904, proposes to give to the gold-bearing metamorphic series of Nova Scotia the name "Meguma series;" to the upper or slate member, the name "Halifax formation;" and to the lower or quartzite member, the name "Goldenville formation." He describes in detail the deposition of the Meguma series.

WOODMAN,[70] in 1908, discusses the probable age of the Meguma (gold-bearing) series of Nova Scotia and concludes it to be pre-Cambrian. The fossils described for the series are partly inorganic, and such as may be organic have little value in determining the age of the series. Lithological resemblances are held to have little value in correlation. The bases for reference to the pre-Cambrian are (1) strong unconformity between these rocks and the overlying Ordovician, Silurian, and Devonian; (2) strong evidence of folding and doming of the Meguma series and the development of interbedded veins before the deposition of the Ordovician; (3) the great thickness of the series, which is four times as great as any of the Cambrian in eastern Canada or Newfoundland; and (4) the fact that the intrusives in the Meguma series are all abyssal, as contrasted with the rhyolitic and basaltic types in the younger rocks.

SUMMARY OF PRESENT KNOWLEDGE.

SOUTHEASTERN NOVA SCOTIA.

In southeastern Nova Scotia the gold-bearing series occupies 8,500 square miles. The sedimentary rocks, covering 5,000 square miles, which are estimated to have a thickness of 26,400 feet, consist of conglomerates, quartzites, clay slates, mica slates, and mica schists. The lower 15,840 feet are chiefly quartzite, and the upper 10,560 feet are a graphitic and ferruginous slate. These sedimentary rocks are intruded by great masses of granite, and adjacent to them, and due to their metamorphic influence, are the mica slates and mica schists. The slates and quartzites are folded into sharp undulations and are cut by a regional slaty cleavage. In the more disturbed parts of the area the bedding is not easily recognized.

The slates and quartzites, the "gold-bearing series," are not found in such structural relations with the early fossiliferous rocks as make a satisfactory correlation possible. Dawson, in 1850, places them as "Lower Silurian" or pre-Silurian. Later, in his Acadian Geology, they are classified as "Lower Silurian," although it is stated that no fossils are found in them. Faribault subsequently called them "Lower Cambrian," citing as evidence the presence of the obscure fossil *Eophyton*, discovered by Selwyn. Dawson found no fossil evidence for his reference of this series to the "Lower Silurian;" and it is remarked by Silliman that immediately overlying rocks containing fossils have never been found. Although Hind in 1870 says that the fossiliferous "Upper Silurian" conformably overlies the gold-bearing series, this statement has been found nowhere else, and later observers have not repeated it, so that it may be considered very doubtful. Although no well-defined fossils have been found, Faribault now believes the gold-bearing sediments to be Cambrian, because of their analogy with the Harleck grit and *Lingula* flag series of North Wales, the auriferous Cambrian of Quebec, and Murray's Intermediate series of Newfoundland. Finally, Woodman, after a careful sifting of evidence, has concluded that the series is pre-Cambrian.

Hence, so far as definite knowledge is concerned, the gold-bearing series may be as late as Cambrian; but it is believed that the probability is strongly in favor of their Algonkian age. Bearing in this direction is the abundance of fossils in the lower Cambrian of southern New Brunswick and Cape Breton and in the lower Cambrian of Newfoundland to the northeast. The extreme scarcity of fossils in the rocks in question renders it probable that they are older than the fossil-bearing Cambrian rocks of the same region. They are much thicker than the known Cambrian rocks of New Brunswick and Newfoundland. Also in Newfoundland the lower Cambrian rocks rest unconformably upon a great series of slates and quartzites, in most respects similar to the gold-bearing series of Nova Scotia. In Newfoundland these are certainly Algonkian, and it seems highly probable that the similar rocks in Nova Scotia were deposited at the same time, the two districts being parts of the same geological province. Woodman cites also the magnitude of the unconformity at the base of the Ordovician, the great folding and veining suffered by the gold-bearing slates and not by the Ordovician, and finally difference in character of intrusives.

Dawson is uncertain whether the more crystalline mica schists and gneisses, which have a somewhat widespread occurrence in southern Nova Scotia, are to be regarded as older than the gold-bearing slates. Hind, in 1870, maintained that a set of older schists and gneisses lie unconformably below the slates on the Halifax and Windsor Railway; and further, that this set of schists and gneisses is unconformably above another series which he referred to the "Laurentian." As no subsequent observer has mentioned the first of these unconformities, and as it occurs at so readily accessible a place, it may well be considered doubtful whether the facts were rightly interpreted. As suggested by Faribault, it does not appear at all improbable that the gneisses associated with the gold-bearing slates are due to dynamic and contact metamorphism of the intruding granite. The coarsely crystalline rocks which Hind referred to the Laurentian are certainly the series which Dawson and other observers regard as later granitic eruptions, and the unconformity mentioned is perhaps an eruptive unconformity.

NORTHWESTERN NOVA SCOTIA.

In northwestern Nova Scotia and Cape Breton is the following ascending succession, as given by Fletcher: (1) Syenites, gneisses, felsites, and quartzites; (2) George River series, consisting of crystalline limestone interstratified with mica schist, quartzite, conglomerates, felsite, syenite, and diorite. By Fletcher and by Gilpin the George River "series" is regarded as resting unconformably upon the lower rocks. From the description it is clear that some of the syenites and other massive rocks intrude the sedimentaries, but whether any older rocks than those of sedimentary origin are to be found in the region is undetermined. The Algonkian may be represented by the clastics, and the Archean is doubtfully present. Some of the granites may be even Paleozoic.

The Etcheminian group of this district, at first described by Matthew as pre-Cambrian, was later found by him to contain Cambrian fauna. The volcanics into which the group grades below (correlated with the Coldbrook of New Brunswick) contain slates with Cambrian fossils, and hence this group of volcanics, with the Etcheminian, is classed as Cambrian.

Hartley, in 1870, suggests the Laurentian age of the crystalline limestones and syenite of St. Amo's, Cape Breton. With commendable caution Robb, in 1876, only says of this older series that it is pre-Carboniferous. Later, Fletcher, on lithological grounds, correlated it with the Laurentian of Canada, and, like the original area of the Laurentian, the Ottawa rocks, he divided it into an "Upper" and a "Lower Laurentian," the lower consisting of various massive and laminated rocks, all presumably of igneous origin whatever their age, and the upper group including all limestones, sandstones, slates, and conglomerates—that is, all which are certainly clastic in character. Associated with this upper group are eruptives of the same character as those found in the "Lower Laurentian."

These two parts of the Laurentian were first described as in apparent unconformity. The detailed evidence for this conclusion it has not been possible fully to give in the foregoing summary. A close scrutiny of the evidence seems to point more strongly toward the later intrusive character of the so-called "Lower Laurentian," but it is not certain that a portion of the so-called "Lower Laurentian" may not be of greater age than the clastic "Upper Laurentian" rocks.

The gold-bearing series referred to the pre-Cambrian in southern Nova Scotia is nowhere found in contact with the pre-Cambrian of northern Nova Scotia and Cape Breton. As has been said, we only know that the gold-bearing slates are unconformably below the Carboniferous, but we believe them to be pre-Cambrian. The supposed pre-Cambrian rocks of northern Nova Scotia and Cape Breton are known only to be unconformably below the *Paradoxides*-bearing slates.

SECTION 3. NEWFOUNDLAND.

SUMMARY OF LITERATURE.

Jukes,[71] in 1843, divides the lower formations of Newfoundland, in descending order, into an upper slate formation, a lower slate formation, and a gneiss and mica slate formation. The igneous rocks consist of various kinds of trap, greenstone, serpentine, hypersthene, porphyry, syenite, and granite. The upper slate formation is believed to be lower than the coal formation, although nowhere found in contact with it. The thickness of the upper slate must be many hundreds of feet. In one instance beds of upper slate rest unconformably upon those of the lower slate formation. The mica slate and gneiss or quartz rock, chlorite slate, and Primary limestone occur together. Nearly the whole of the province of Avalon is composed of the lower slate formation. On Conception Bay at several places beds of variegated slate overlap and cover the edges of the lower slate in a perfectly unconformable position.

On Newells Island the junction of the gneiss and mica slate with the granite is found. The mica slate in approaching the granite becomes more crystalline and gneisslike in certain layers. On continuing to approach the granite there appear thin beds of granite, which are not veins from the granite, but an integral part of the beds. The alternations increase in frequency, until, after passing over the edges of many beds, the red and flesh-colored, perfectly crystalline granite, with no appearance of any lamination or bedding whatever, is imperceptibly reached. In the granite itself, for some distance from the junction, nodular masses of black rock, consisting of minute scales of mica, were observed. In other places the mica slate and gneisses alternate with each other and are cut by distinct granite veins.

The cleavage of the slate rocks is frequently parallel to the planes of stratification, but often cuts them at all angles. The strike of the cleavage is in a great majority of instances parallel to the strike of the beds, but not invariably so. The cleavage is much more constant as regards strike and dip than are the beds. The dip of the cleavage is never at a less angle than 45°, while in the majority of instances it is nearly perpendicular. Its strike was not in any instance found to vary more than 10° or 15° from a north-northeast and south-southwest bearing. Certain of the granites are newer than the mica slate and gneiss. Also some of the porphyritic granite is more modern than some of the shales. In other cases the red igneous rock, generally the syenite, is in all probability one of the oldest rocks in the country, as no veins were observed to proceed from it into the adjoining formations, and a rounded pebble of a precisely similar rock is found in a bed belonging to the older slate formation in Great Placentia.

Murray,[72] in 1865, describes the geology of the northeastern part of Newfoundland. Here is found a Laurentian group, which consists mostly of gneisses, but contains in places layers of mica slate and whitish quartzite. These rocks are placed in the Laurentian because they have a lithological resemblance to the Laurentian of Canada, and because they are covered unconformably by the Lower Silurian strata. No crystalline limestones such as are associated with the Laurentian of Canada are found interstratified with the gneisses. The rocks of the overlying Potsdam and Quebec group are fossiliferous.

Murray,[73] in 1868, gives an account of a part of the coast of Notre Dame Bay. A section of rocks in this locality, consisting of slates, quartzites, and dolomites, with various eruptives, is referred in part to the Quebec group. Among the intrusives are syenite and diorite. At Lascie Harbor the rocks are mainly gneiss, resting unconformably upon which is a great mass of unstratified quartzite.

Murray,[74] in 1868, treats of the peninsula of Avalon. Here is found a gneiss which is referred to the Laurentian. Intermediate between this gneiss and the Lower Silurian strata is a great thickness of slates and quartzites, which are referred to the Huronian. Resting unconformably upon these rocks are others containing Potsdam fossils.

In the Laurentian are placed the gneisses of Conception Bay, the masses of granite, syenite, and porphyries of St. Johns Peninsula described by Jukes, and the granites of Placentia Bay and Sound Island. These rocks are like those referred to the Laurentian in the great northern peninsula. The intermediate system consists of diorites, quartzites, slate conglomerates, slate, and sandstone, the whole series in Conception Bay being more than 11,000 feet thick. This series resembles lithologically the Huronian system of Canada in a high degree, although it may be admitted that lithological relations are of secondary importance in correlating rocks which are remote from each other. In one member of the group is a fossil, designated *Aspidella*, of a low order of existence, which leads to the conclusion that the system is probably Cambrian. This series of rocks occupies by far the greater part of the peninsula of Avalon. The lower rocks in all cases pitch at a very high angle to the horizon, the prevailing inclination being eastward, while the upper formation, except where disturbed by eruptives, is either in a perfectly horizontal attitude or only slightly inclined. The lower series is also marked for its general absence of lime, while the upper formation is nearly all more or less calcareous. Further, the Potsdam rocks were found to overlie unconformably the lower slates at Manuels Brook and at Brigus South Head. The Nova Scotia gold-bearing rocks are lithologically like the system referred to the Huronian in Newfoundland, although they have been referred to the Lower Silurian.

MURRAY,[75] in 1870, finds the rocks of Bonavista Bay to consist largely of slates, slate conglomerates, quartzites, and diorites, intersected by intrusive granite or syenite, trap, and quartz veins. This series has such a close lithological resemblance to the intermediate system of Avalon that there is no doubt of their identity. These rocks also occur between the gneiss and the Paleozoic formations of Trinity Bay.

HOWLEY,[76] in 1870, describes sundry parts of the coast. The rocks of Cape Ray and the extreme head of Conception Bay are of a gneissoid character. Granite, syenite, and trap are interbanded with quartzite. On Great Miquelon Island is found gneiss, supposed to be of Laurentian age. Greenstones and granite break at various places through the stratified rocks.

MURRAY,[77] in 1873, gives a further account of the Avalon Peninsula. The line of contact between the Huronian and more recent rocks in Trinity Bay is obscure and difficult to detect, and here *Aspidella* is very useful in deciding to which series the rocks belong. The rocks on the west coast of Trinity Bay are correlated with the Huronian on lithological evidence. The rocks here are in some respects different from those on St. Johns Peninsula, but this difference seems to be due to the intense volcanic activity which has affected the western part of Avalon. Dikes of various kind intersect the formation, and the strata are in places volcanic conglomerates, volcanic ashes, etc. The rocks of Brigue, described in the report for 1868, are found to contain several beds which are crowded with *Aspidella*.

MURRAY,[78] in 1873, finds gneissic rocks at several localities in St. Georges Bay. Associated with these are labradorite and other anorthosite rocks which belong to the upper Laurentian system. Also, on Great Codroy River is found white crystalline limestone with graphite, which is regarded as a further indication of the presence of this division of the Laurentian.

MURRAY,[79] in 1875, finds on Gander Lake micaceous slate, fine-grained granite, and gneiss, which are correlated with the Laurentian gneiss of Bonavista Bay.

HOWLEY,[80] in 1877, further examines Gander Lake and River and finds chlorite slates, diorites, and mica slates which contain no organic remains, and which on account of their lithological character and the serpentine they contain are provisionally placed with the Quebec group. At Upper Gambo Pond and along Riverhead Brook are found sandstones and quartzites which at some places pass almost imperceptibly into gneiss, which rocks, with the associated micaceous slates, are provisionally placed with the Huronian.

HOWLEY,[81] in 1882, further describes the intermediate system of Huronian rocks. These metamorphic rocks occupy the greater part of the peninsula of Avalon. They rest upon a nucleus of Laurentian gneiss and are succeeded by fossiliferous beds of the Primordial age which skirt the shores of the bays and are found to rest unconformably on the basset edges of the upturned and altered Huronian, and occasionally in contact with the still older Laurentian. The intermediate rocks are found to be gently folded, so that the same strata are repeated several times. Associated with these Huronian rocks are trappean beds and volcanic ash. Contained in them are found two fossils, *Aspidella terranovica* and *Arenicolites spirales*. The last-named fossil is said to occur in the Primordial rocks of Sweden. These fossils give important assistance in the ready recognition of the Huronian. The gneissic rocks which have been described as being members of the Laurentian system protrude through the Huronian strata by which they are surrounded. Cutting the Huronian rocks is found a series of granitoid and other plutonic rocks which obliquely intersect the eastern part of the peninsula, including the Laurentian gneiss. A second great igneous intrusion cuts all of the rocks of the western part of the peninsula, including the Potsdam sandstone. The intrusions of the eastern peninsula are taken to be of older date than the trap of the western peninsula, although probably later than Huronian, as the former is never found to cut the Potsdam sandstone.

Walcott,[82] in 1889, corroborates the unconformity between the series referred by Murray to the Huronian and the overlying series called Potsdam. The latter is found to contain the *Olenellus* fauna below the *Paradoxides* and is placed as lower Cambrian.

Walcott,[83] in 1899, states that the Avalon series of Newfoundland includes all the pre-Cambrian sedimentary rocks of that area. Overlying them are Cambrian strata carrying *Olenellus* fauna. The *Aspidella* of the Momable slates is probably of organic origin, but it may be questioned. Other reported forms are inaccessible for study.

Walcott,[84] in 1900, reports on the results of an examination of Cambrian and pre-Cambrian formations on Smiths Sound, Newfoundland, during the summer of 1899. At Smith Point he found the *Olenellus* fauna 369 feet below the summit of the Etcheminian, and one of its types, *Coleoloides typicalis*, in the basal bed of the Cambrian on the south side of Random Island. This retains the Etcheminian of Newfoundland in the Lower Cambrian.

The Random terrane, so called from a typical section on Random Sound, is a series of sandstones, quartzitic sandstones, and sandy shales, resting conformably upon the Signal Hill conglomerate (which was formerly supposed to represent the top of the Avalon or Algonkian series) and extending up to the base of the Cambrian. The Random terrane is thus the upper member of the Avalon series and fills a portion, if not all, of the gap between the Signal Hill conglomerate and the Cambrian. The Cambrian rests on the Random terrane with a thin belt of conglomerate. The thickness of the terrane is probably 1,000 feet. In one horizon in the terrane were found several varieties of annelid trails, including a variety about 5 mm. broad, a slender form ½ mm. broad, and an annulated trail 2 to 3 mm. in width.

An examination of the form known as *Aspidella terranovica* found in the Momable terrane of the Avalon series proved the supposed fossil to be a spherulitic concretion, and this removes it from among the possible pre-Cambrian forms of life.

Daly,[85] in 1903, describes variolitic pillow lava from Newfoundland, and calls attention to the widespread occurrence of this or similar rocks, frequently called ellipsoidal greenstones, in Minnesota, New Brunswick, California, and Michigan.

SUMMARY OF PRESENT KNOWLEDGE.

Granites and gneisses, with occasional bands of limestone and anorthosite intrusions, form broad northeast-southwest bands which seem to serve as a skeleton upon which the island is built. The series has been mapped as "Laurentian" by Murray and Howley, but may contain younger rocks. Between them and northwest of them are Paleozoic rocks, and to the southeast, forming a large part of the southeastern part of the island, including the peninsula of Avalon, are pre-Cambrian sedimentary rocks, basic volcanics, and various intrusives. The sedimentary group, called the Avalon group, consists of quartzites, slate conglomerates, slates, and sandstones. These are gently folded and slightly metamorphosed in the upper portions. In the lower part of the group basic volcanics and various intrusives are abundant, especially on the west side of the peninsula of Avalon and the adjacent portion of the main island, the folding is closer, and metamorphism is correspondingly great. The group was found by Murray to be more than 11,000 feet thick. It contains two so-called fossils, *Aspidella terranovica* and *Arenicolites spirales*, but these have been held by Walcott not to be organic. In the Random formation, the upper member of the Avalon group, Walcott found annelid trails.

Howley separates from the Avalon group certain of the highly metamorphosed sediments associated with the basic volcanics near its base, and calls them "Huronian," a term which Murray originally applied to all that great series of altered sediments and partly volcanic rocks between the Laurentian proper and the lower Cambrian. Howley provisionally draws the line between the Avalon and the "Huronian" series at about the point where the distinctly volcanic rocks cease and the more regular sedimentary strata are well defined. No unconformity is known to exist.

From Howley's description and maps (not published), and from a casual examination by the junior author, it is suggested that some so-called "Huronian" rocks are very similar in some of their aspects to the Keewatin of the Lake Superior country.

Overlying the Avalon group is a series of red and green shales with interbedded limestones of Cambrian age. These have been correlated by Matthew with the Etcheminian group of New Brunswick and were supposed to be pre-Cambrian, but subsequent work by Walcott showed them to contain Cambrian fossils.

The Avalon group is therefore correlated with the Algonkian. The lower metamorphosed part, with the basic volcanics (Howley's Huronian), is included. There is a possibility that this part should be correlated with the Keewatin, though no unconformity is yet recognized between it and the overlying sedimentary Avalon. The relations of the "Laurentian" granites and gneisses to the Avalon rocks are not known, although some of them are certainly intrusive. The term "Laurentian" is here used in the broader sense allowed in the recent international committee report, to include not only pre-Algonkian rocks but unseparated later rocks.

In all probability the Avalon group, as explained on a previous page, is equivalent to the gold-bearing quartzites and slates of southeastern Nova Scotia. Both of these may be equivalent to one or both of the clastic series of southern New Brunswick. In degree of metamorphism and in the presence of volcanic rocks the areas are somewhat similar.

SECTION 4. GASPE PENINSULA.

SUMMARY OF LITERATURE.

ELLS,[86] in 1885, describes the pre-Cambrian rocks of the Gaspe Peninsula. These are confined to the Shickshock Mountains. They are garnetiferous gneiss, hornblendic, chloritic, and micaceous schists, epidosite, etc. These rocks are so like the pre-Cambrian as seen in New Brunswick and other parts of Canada that they are removed from the Quebec group and assigned to an older horizon. Serpentines, diorites, and granites are intrusives, a part of them later in age than Devonian.

Low,[87] in 1885, also describes the pre-Cambrian rocks of the Gaspe Peninsula. They are represented by the metamorphic schists and slates of the Shickshock Mountains, among which are serpentine, and several beds of limestone, one of them being 90 feet thick. Great masses of granite and dikes of trap are found in these series. The granites are evidently of later date than the Silurian and Devonian rocks, as fragments of these are inclosed in them, and the adjacent stratified rocks show alteration.

SUMMARY OF PRESENT KNOWLEDGE.

In the Shickshock Mountains, on the Gaspe Peninsula, are garnetiferous gneiss, hornblendic, chloritic, and micaceous schists, slates, limestones, and serpentine. Intruded in these rocks are found great masses of granite and dikes of trap newer than the Silurian or Devonian, as shown by inclosed fragments of these rocks. No attempt has been made to subdivide the rocks of this area into series. The character of the rocks mentioned makes it probable that Algonkian rocks occur here, and the Archean may also be represented.

NOTES.

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[2] Second report on the geological survey of the Province of New Brunswick, by Abraham Gesner, pp. 76.

[3] Third report on the geological survey of the Province of New Brunswick, by Abraham Gesner, pp. 88.

[4] Fourth report on the geological survey of the Province of New Brunswick, by Abraham Gesner, pp. 101.

[5] Report on the geological survey of the Province of New Brunswick, with a topographical account of the public lands, by Abraham Gesner, pp. 88.

[6] Report on the agricultural capabilities of the Province of New Brunswick, by J. F. W. Johnston, pp. 262, accompanied by a soil map.

[7] Observations on the geology of southern New Brunswick, by L. W. Bailey, Geo. F. Matthew, and C. F. Hartt, 1865, pp. 158, with a geological map.

[8] On the Azoic and Paleozoic rocks of southern New Brunswick, by G. F. Matthew. Quart. Jour. Geol. Soc., London, vol. 21, 1865, pp. 422–434. See also Canadian Naturalist, 2d ser., vol. 3, 1868, pp. 387–391.

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[10] Remarks on the age and relations of the metamorphic rocks of New Brunswick and Maine, by George F. Matthew and L. W. Bailey. Proc. Am. Assoc. Adv. Sci., 18th meeting, 1869, pp. 179–195.

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[14] Report of geological observations in southern New Brunswick, by L. W. Bailey, G. F. Matthew, and R. W. Ells. Rept. Prog. Geol. Survey Canada, 1875–76, pp. 348–368.

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[16] Report on the Lower Carboniferous belt of Albert and Westmoreland counties, New Brunswick, including the Albert shales, by L. W. Bailey and R. W. Ells. Idem, pp. 351–395, with a map.

[17] Report on the pre-Silurian rocks of Albert, eastern Kings, and St. John counties, southern New Brunswick, by R. W. Ells. Rept. Prog. Geol. Survey Canada, 1877–78, pp. 1–13 D.

[18] Report on the pre-Silurian (Huronian) and Cambrian, or Primordial Silurian rocks of southern New Brunswick, by L. W. Bailey. Idem, pp. 1–34 DD.

[19] Report on the Upper Silurian and Kingston (Huronian) of southern New Brunswick, by G. F. Matthew. Idem, pp. 1–6 E.

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[23] Report on the geological formations of eastern Albert and Westmoreland counties, New Brunswick, and of portions of Cumberland and Colchester counties, Nova Scotia, by R. W. Ells. Rept. Prog. Geol. Survey Canada for 1885, new ser., vol. 1, pp. 5–71 E, with a map.

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[25] President's annual address; *Eozoon* and other low organisms in Laurentian rocks at St. John; On the occurrence of sponges in Laurentian rocks at St.

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[31] Additional notes on the Cambrian of Cape Breton, by G. F. Matthew. Bull. Nat. Hist. Soc. New Brunswick, No. 20, vol. 4, pt. 5, 1902, pp. 377–426.

[32] Charlotte County, New Brunswick, by R. W. Ells. Summary Rept. Geol. Survey Dept. Canada, for 1903, 1904, pp. 150–160.

[33] Geology of Charlotte County, New Brunswick, by R. W. Ells. Summary Rept. Geol. Survey Dept. Canada, for 1904, 1905, pp. 271–279.

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[35] On the geology of a part of New Brunswick, by Charles Robb. Rept. Prog. Geol. Survey Canada, 1866–1869, pp. 172–209, with a sketch map.

[36] Supplementary report on the geology of northwestern New Brunswick, by Charles Robb. Rept. Prog. Geol. Survey Canada, 1870–71, pp. 241–251.

[37] Report on the geology of northern New Brunswick, embracing portions of the counties of Restigouche, Gloucester, and Northumberland, by R. W. Ells. Rept. Prog, Geol. and Nat. Hist. Survey Canada, 1879–80, pp. 1–47 D.

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[43] Remarks on the mineralogy and geology of the peninsula of Nova Scotia, by Charles T. Jackson and Francis Alger, 1832, pp. 116, with a colored map.

[44] On the geology of Cape Breton, by Richard Brown. Quart. Jour. Geol. Soc., London, vol. 1, 1845, pp. 23–26, 207–213, with a geological map.

[45] On the metamorphic and metalliferous rocks of eastern Nova Scotia, by J. W. Dawson. Idem, vol. 6, 1850, pp. 347–364, with a geological map of a part of Nova Scotia.

[46] Acadian geology, by J. W. Dawson, 1st ed., 1855, pp. 388, with a map; 2d ed., 1868, pp. 694, with a map; 3d ed., 1878, pp. 694, supplement, pp. 102, with a map. In the abstract the second edition is followed.

[47] Nova Scotia gold fields, by J. S. Campbell, 1863.

[48] Report on the Waverly gold district, by Henry Youle Hind, 1869, pp. 62, with geological maps and sections.

[49] Report on the Sherbrooke gold district, together with a paper on the gneisses of Nova Scotia, by Henry Youle Hind, 1870, pp. 79, with a geological map. See also On two gneissoid series in Nova Scotia and New Brunswick, supposed to be the equivalents of the Huronian (Cambrian) and Laurentian. Quart. Jour. Geol. Soc., London, vol. 26, 1870, pp. 468–479, with plate. On the Laurentian and Huronian series in Nova Scotia and New Brunswick. Am. Jour. Sci., 2d ser., vol. 49, 1870, pp. 347–355.

[50] Report on the gold property of the New York and Nova Scotia Gold Mining Company, with an introduction on the general structure and geology of the Nova Scotia gold fields, by B. Silliman, jr., New York, 1864.

[51] Notes and observations on the gold fields of Quebec and Nova Scotia, by A. R. C. Selwyn. Rept. Prog. Geol. Survey Canada, 1870–71, pp. 252–282.

[52] On explorations and surveys in Cape Breton, Nova Scotia, by Charles Robb. Rept. Prog. Geol. Survey Canada, 1874–75, pp. 166–266, with two geological maps.

[53] Report of explorations and surveys in Cape Breton, Nova Scotia, by Hugh Fletcher. Rept. Prog. Geol. Survey Canada, 1875–76, pp. 369–418, with a geological map.

[54] Report on the geology of part of the counties of Victoria, Cape Breton, and Richmond, Nova Scotia, by Hugh Fletcher. Rept. Prog. Geol. Survey Canada, 1876–77, pp. 402–456, with a map.

[55] Acadian geology, by J. W. Dawson. Third ed., 1878, pp. 694, supplement, pp. 102, with a map.

[56] Report of explorations and surveys in Cape Breton, Nova Scotia, by Hugh Fletcher. Rept. Prog. Geol. Survey Canada, 1877–78, pp. 1–32 F, with a geological map.

[57] Report on part of the counties of Richmond, Inverness, Guysborough, and Antigonish, Nova Scotia, by Hugh Fletcher. Rept. Prog. Geol. and Nat. Hist. Survey Canada, 1879–80, pp. 1–125 F.

[58] Report on the geology of northern Cape Breton, by Hugh Fletcher. Rept. Prog. Geol. and Nat. Hist. Survey and Museum Canada, 1882–1884, pp. 1–98 H, with geological map of Cape Breton.

[59] The geology of Cape Breton Island, Nova Scotia, by Edward Gilpin. Quart. Jour. Geol. Soc., London, vol. 42, 1886, pp. 515–526, with a geological map of Cape Breton.

[60] Report on geological surveys and explorations in the counties of Guysborough, Antigonish, Pictou, Colchester, and Halifax, Nova Scotia, from 1882 to 1886, by Hugh Fletcher. Rept. Geol. and Nat. Hist. Survey Canada, 1886, new ser., vol. 2, pp. 1–128 P, with two plates.

[61] Report on the Lower Cambrian rocks of Guysborough and Halifax counties, Nova Scotia, by E. R. Faribault. Idem, pp. 129–163 P.

[62] On the Eozoic and Paleozoic rocks of the Atlantic coast of Canada, in comparison with those of western Europe and of the interior of America, by J. W. Dawson. Quart. Jour. Geol. Soc., London, vol. 44, 1888, pp. 797–817, and note, vol. 45, p. 80, Proc.

[63] Preliminary report of geological investigations in southwestern Nova Scotia, by L. W. Bailey. Ann. Rept. Geol. Survey Canada for 1892–93, new ser., vol. 6, pt. Q, 1895, pp. 21, with map.

[64] Report on the geology of southwest Nova Scotia, by L. W. Bailey. Ann. Rept. Geol. Survey Canada for 1896, new ser., vol. 9, pt. M, 1898, pp. 154, with geological map.

[65] The gold measures of Nova Scotia and deep mining, by E. R. Faribault. Canadian Min. Inst., vol. 2, 1899, pp. 119–130.

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[67] Additional notes on the Cambrian of Cape Breton, by G. F. Matthew. Bull. Nat. Hist. Soc. New Brunswick No. 20, vol. 4, pt. 5, 1902, pp. 377–426.

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[71] General report of the geological survey of Newfoundland for the years 1839 and 1840, by J. Beete Jukes, pp. 160, with maps.

[72] The geology of the northeastern part of Newfoundland, by Alexander Murray. Rept. Geol. Survey Newfoundland for 1864, pp. 4–50.

[73] An account of a part of the coast of Notre Dame Bay, by Alexander Murray. Rept. Geol. Survey Newfoundland for 1865, pp. 111–136.

[74] The peninsula of Avalon, by Alexander Murray. Rept. Geol. Survey Newfoundland for 1868, pp. 137–186.

[75] The rocks of Bonavista Bay, by Alexander Murray. Rept. Geol. Survey Newfoundland for 1869, pp. 187–209.

[76] Examination of sundry parts of the coast, by James P. Howley. Rept. Geol. Survey Newfoundland for 1870, pp. 210–249.

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[79] Rept. Geol. Survey Newfoundland for 1874, pp. 351–409.

[80] Rept. Geol. Survey Newfoundland for 1876, pp. 423–462.

[81] Report of James P. Howley for the year 1881. Rept. Prog. Geol. Survey Newfoundland for 1881, pp. 6–23, with geological maps of the peninsula of Avalon.

[82] Stratigraphic position of the *Olenellus* fauna in North America and Europe, by Charles D. Walcott. Am. Jour. Sci., 3d ser., vol. 37, 1889, pp. 374–392; vol. 38, 1889, pp. 29–42.

[83] Pre-Cambrian fossiliferous formations, by Charles D. Walcott. Bull. Geol. Soc. America, vol. 10, 1899, pp. 199–244.

[84] Random, a pre-Cambrian upper Algonkian terrane, by Charles D. Walcott. Bull. Geol. Soc. America, vol. 11, 1900, pp. 3–5.

[85] Variolitic pillow lava from Newfoundland, by Reginald A. Daly. Am. Geologist, vol. 32, 1903, pp. 65–78.

[86] Report on explorations and surveys in the interior of Gaspe Peninsula and Prince Edward Island, by R. W. Ells. Rept. Prog. Geol. and Nat. Hist. Survey and Museum Canada, 1882–1884, pp. 1–34 E.

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CHAPTER VIII.

THE GREAT NORTHERN INTERIOR OF CANADA.

SUMMARY OF LITERATURE.

STEINHAUER,[1] in 1814, gives localities for labradorite on the coast of Labrador.

McCULLOGH,[2] in 1819, describes as coming from Baffin Bay, 70° 37′, granite, gneiss, and graywacke schist.

RICHARDSON,[3] in 1823, describes clay slate as occurring in the northern arm of Great Slave Lake. North of Great Slave Lake the granite formation continues for a considerable distance toward Fort Enterprise, but foreign beds increase in amount northward. In this region in places mica slate prevails and in other places the granite contains beds of mica slate. Gneiss appears to exist throughout the great district to the east of Coppermine River. About Fort Enterprise are numerous hills capped by red granite, around which, on the acclivities, gneiss is wrapped in mantle form. The rocks of this district include granite, micaceous and hornblendic gneiss, greenstone, mica slate, and clay slate. At Point Lake are found graywacke slate, clay slate, and Transition greenstone slate, as well as Transition conglomerate, the fragments of which appear to consist of the same material as the bases. In the part of the region of Coppermine River between Point Lake and the sea are found granite, syenite, gneiss, clay slates, and hills of trap. North of latitude 66° 45′ 11″ are found red and gray sandstones, compact feldspar rock, granular foliated limestone, trap rock, and greenstone which constitutes the Copper Mountains. In these mountains are amygdaloids which contain amygdules of pistacite and calc spar, scales of copper being generally disseminated through the rock. In this region were also found masses of native copper and prehnite. The shores of Bathurst Inlet are partly of granite and gneiss and partly of later rocks. On the road from Bathurst Inlet to Point Lake and Fort Enterprise, beyond Hoods River, the rocks are entirely gneissic or granitic.

PARRY,[4] in 1824, found granitic and gneissic rocks to occupy the whole southern part of the east shore of Melville Peninsula and to continue northward behind a tract of limestone country, forming a range of mountains in the center of the peninsula to Hecla-and-Fury Strait. They also form the south shore of this strait, most of the islands adjacent to it, and apparently the whole eastern shore of the adjacent south part of Cockburn "Island."

KONING,[5] in 1824, describes the most characteristic rock collected by Captain Parry on the west coast of Baffin Bay as gneiss and micaceous quartz rock, with some ambiguous granitic compound in which hornblende seems to enter as a subordinate ingredient.

LYON,[6] in 1825, describes Cape Fullerton, on the main shore west of Southampton Island, to be composed of rugged red and gray granitic rocks with the strata running in a northwest direction.

JAMESON,[7] in 1826, states that the material collected by Captain Parry shows that the west coast of Davis Strait and Baffin Bay, south of Lancaster Sound, consists of Primitive rocks, among which are gneiss, mica slate, hornblende slate, granite limestone, hornblende rock, and greenstone. All these rocks are more or less distinctly stratified and numberless transitions from one into the other were observed.

RICHARDSON,[8] in 1828, describes the rocks of the Coppermine River series as extending westward to the Height of Land and consisting chiefly of sandstone and conglomerates with granite and porphyry. The southeast extremity of McTavish Bay consists of red granites and gneisses. At the mouth of Dease River and the northeast extremity of the lake the prevailing formation is granitic and gneissic. On Mount Fitton, along the Arctic coast west of Mackenzie River, the mountain range consists of graywacke slates which are considered Transition rocks.

LESLIE, JAMESON, and MURRAY (HUGH),[9] in 1830, mention in the region of Southampton Island, Melville Peninsula, and Hecla-and Fury Strait, as prominent varieties of rock, granite, gneiss, mica slate, clay slate, chlorite slate, Primitive trap, serpentine, limestone, and porphyry. The Primitive range bordering the east coast of Baffin Land is a continuation of the Labrador coast; and on the west coast of Davis Strait and Baffin Bay, south of Lancaster Strait, Primitive rocks preponderate, including gneiss, mica slate, and granite.

ROSS,[10] in 1835, finds granitoid and gneissic rocks to occupy exclusively the coast line and adjacent islands of the Boothian and Melville Peninsula south of 70° 35′.

FITTON,[11] in 1836, describes the north side of Great Slave Lake from the entrance of the north arm westward as consisting mainly of gneiss, porphyry, and granite. The large islands and promontory of the eastern part of the lake are of the trap formation. These are compared to the Coppermine series. Pebbles of jasper conglomerate were collected near the west end of the lake, but the rock was not seen in place. The rocks on the route from Great Slave Lake northeastward by Clinton-Golden and Aylmer lakes and Great Fish River to the Arctic coast are different varieties of granite and gneiss.

BACK,[12] in 1838, describes granite as occurring in two places along the southeastern coast of Southampton Island.

BAYFIELD,[13] in 1840, describes granite rocks as occupying the following districts: Along the St. Lawrence from the Saguenay to Pointe de Monts, a distance of 130 miles; from Pointe de Monts to the Seven Islands, a distance of 60 miles; the mainland to the east of Mingan Islands and opposite Ste. Genevieve Island, where the country for many miles inland is composed of low granite mounds; the coast from Ste. Genevieve east to Cape Whittle, longitude 60° W., latitude 50° 10′ N. The granites are in part hornblendic and in part nonhornblendic. At Ste. Genevieve was observed hypersthene and Labrador feldspar. The granitic rocks are regarded as unstratified. They are traversed by trap veins, insignificant in size as compared with the immense size of the Lake Superior granite masses. Reposing horizontally on the granites on the east side of Pillage Bay and Mount Ste. Genevieve are limestones. The islands of the south shore of the St. Lawrence and the south coast from Saguenay to Cape Rozier are composed of alternating strata of graywacke and slate dipping to the south at angles varying from 30° to 90°.

SIMPSON,[14] in 1843, applies the name Trap Point to the Kent Peninsula. After an interval of low ground to the east granite forms the coast line.

LOGAN,[15] in 1850, describes a metamorphic group of rocks in the vicinity of Bay St. Paul, Murray Bay, and White Cape on St. Lawrence River. The predominant rocks are mica gneisses and hornblende gneisses. No crystalline limestones were noted.

RAE,[16] in 1850, finds north of latitude 61° on the west coast of Hudson Bay, beyond Nevills Bay, the shore steep and rugged, being lined with bare Primitive rocks. On the southern shores of the Gulf of Boothia granite occurs in several places, and among the specimens found are gneiss, mica slate, quartz rock, and hornblende slate. Precipitous cliffs of trap were found on Simpson Bay, in latitude 68° 27′.

RICHARDSON,[17] in 1851, states that the eastern side of the north arm of Great Slave Lake is occupied by Primitive rocks, which run across the outlet of Athabasca Lake to the deep, northern arm of Great Slave Lake, and onward by Marten Lake, across the two eastern arms of Great Bear Lake, to the Copper Mountains. On Rae River, which flows into Coronation Gulf near the mouth of the Coppermine, are limestone, quartz rock, and high cliffs of basalt. From the similarity of the various rocks associated in this quarter to those occurring at Pigeon River and other parts of the north shore of Lake Superior the author is inclined to consider that the two deposits belong to the same geological era, both being more ancient than the Silurian. At Rae River and Richardson River, to the northwest of the mouth of the Coppermine, and on the west side of Coppermine River are series of basaltic cliffs.

SUTHERLAND,[18] in 1853, describes the rocks at Cape York and Cape Atholl, latitude 76°, as consisting of sandstones interstratified with volcanic material. On the east coast of Baffin Land, from Lancaster Sound to Cumberland Sound, are crystalline rocks which occupy the whole coast southward to Cumberland Strait.

LOGAN,[19] in 1854, describes the district north of St. Lawrence River, between Montreal and Cape Tourment, below Quebec. To the metamorphic sediments the word Laurentian is applied. It is used to cover all of the prefossiliferous rocks. The name is founded on that given by Garneau to the chain of hills which the Laurentian series compose. At St. Maurice the Potsdam sandstone rests upon the gneiss.

MURCHISON,[20] in 1857, states that Cape Granite, in the Arctic archipelago, is composed of quartz, feldspar, and chlorite, and that with the granite is associated gneiss of the same composition.

KANE,[21] in 1857, states that the rocks of the coast between Rensselaer Harbor and the great Humboldt Glacier (in Peabody Bay) are stratified limestones, sandstones, feldspathic and porphyritic granite passing into gneiss, and in some places trap.

HAUGHTON,[22] in 1857, describes granitic rocks as composing a considerable part of North Greenland, on the north side of Baffin Bay, and constituting the rock of the country at the east side of the island of North Devon. Between Capes Osborne and Warrender the rocks are graphic granite, which passes into a laminated gneiss, and with the gneiss are interstratified beds of garnetiferous mica slate. The whole series is overlain by red sandstones of banded structure. The granitoid rocks are again found on the north side of the island of North Somerset, where they form the eastern boundary of Peel Sound. Cape Granite is the northern boundary of the granite. On Peel Sound and Prince of Wales Island is a dark syenite composed of feldspar and hornblende. This rock is massive and eruptive at Cape McClure, and occasionally gneissic. The Silurian of the Arctic archipelago rests everywhere directly on the granite, with a sandstone, passing into a coarse grit, at its base.

HAUGHTON,[22] in 1859, states that granitoid rocks everywhere underlie the Arctic archipelago. At Montreal Island is a gneiss which exhibits the phenomena of foliation in a marked degree. At Bellots Straits, in latitude 72° north, are found gneissoid granite, graphic granite, and syenite. At Ponds Bay, at the northern extremity of Baffin Land, quartziferous mica schist underlies the Silurian limestone and is interstratified with gneiss and garnetiferous quartz rock inclining 38° WSW. Cape York, on the Greenland coast, is composed of fine-grained granite. At Wolstenholme Sound the granitoid rocks are converted into mica slate and actinolite slate, the two rocks passing into each other by almost insensible gradations. Careys Islands, west of Wolstenholme Sound, are composed of a gneissose mica schist, formed of successive layers of quartz granules and jet-black mica. The mica schist passes into white gneiss. On the islands yellow and white sandstones are also found in small quantity, reposing upon the granitoid rocks.

Lieber,[23] in 1860, describes gneisses, granites, labradorites, etc., found at various localities on the coast of Labrador.

Dawson,[24] in 1861, describes the Laurentian rocks exposed on the coast cliffs of Murray Bay. At one place the succession includes gneiss, white quartz rock, impure limestone, and hornblende slate, but the beds are so inverted that little reliance can be placed on apparent superposition. The crystalline limestone, dolomite, and serpentine are together 14 feet thick. The Silurian rocks rest unconformably upon the Laurentian beds.

Richardson,[25] in 1870, describes the Laurentian and Labradorite rocks on the north shore of the lower St. Lawrence. The Laurentian gneiss has sometimes little appearance of stratification. The dips are high, approaching the vertical. The Labradorite, with moderate dips, rests unconformably upon the Laurentian. At one place there occurs in the gneiss a bed 12 feet thick of coarsely crystalline limestone. The Labradorite rocks have a wide extent. Both the Laurentian gneiss and the Labradorite are cut by granitic veins.

Richardson,[26] in 1872, reports on the prefossiliferous rocks in the country north of Lake St. John. They are classified under two heads: First, Laurentian gneiss, including a little crystalline limestone; second, crystalline schists, consisting of chloritic and epidotic rocks, with dolomites, serpentines, and conglomerates. The Laurentian occupies much the largest area of country and includes gneissic rocks cut by granite veins, limestones, quartzites, and hornblende rocks. The limestones and quartzites are comparatively unimportant, but the former is said to be in thickness not less than 500 or 600 feet. The rocks of the second class immediately succeed the Laurentian near the north end of Lake Abatagomaw. Large expanses of the conglomerate of this series are composed entirely of rounded fragments of Laurentian gneiss of gray and red colors. In some places, without close examination, the conglomerate might be mistaken for the Laurentian gneiss. Sandstones and shales are met with which show lines of deposition. It is remarked that, whatever the geological horizon of this series of rocks, it will be prudent for the present to withhold an opinion until further investigations are made. The only indication as to the geological age of this series is given by an obscure fossil occurring in a limestone which Billings thinks is a coral.

Bell,[27] in 1877, reports on explorations between James Bay and Lakes Superior and Huron. The rocks are described as Huronian on the course followed until the north side of Shatagami Lake is reached, with the reservation that the gneiss just below Pauls Lake may be Laurentian. In this distance the rocks are limestones, quartzite, diorite, chert, slate conglomerate, hornblende schist, pegmatite, syenite, clay slates, and, at Pauls Lake, gneiss. The diorites have a widespread occurrence, and an area of massive syenite continues for several miles in one locality. It is often mixed with crystalline diorite. Beyond Shatagami Lake are several alternations of rocks which are referred to the Huronian and Laurentian, before the fossiliferous series is reached. The conspicuous feature of the last Laurentian belts are large diorite dikes. The junction of the Laurentian and Huronian occurs at Davis's rapid, 51 miles north of the outlet of Lake Kenogamissee.

On the return trip the course followed is by the west branch of Moose River, along toward its headwaters, thence to Michipicoten and Lake Superior. The rocks are chiefly granite and syenite, gneiss, hornblende schists and mica schists, and greenish schists. These are in part referred to the Huronian and in part to the Laurentian, several belts of the Huronian being found. At one place the Huronian is spoken of as passing into the Laurentian. As a result of the work it is shown that an immense area of Huronian rocks runs northward from Lake Huron through the greater part of the distance lying between it and the area of unaltered rocks of the southwest side of James Bay.

DeRance and Fielden,[28] in 1878, state that the Laurentian system is the fundamental one for the region visited by Sir George Nares. At Cape Rawson is an important overlying series which occupies the coast of Grinnell Land from Scoresby Bay to Cape Cresswell, in latitude 82° 40′ north. The rocks are in a series of sharp folds with a general west-southwest strike, the beds being often vertical and frequently cleaved. They consist of jet-black slates, impure limestones traversed by veins of quartz and cherts, and a vast series of quartzites and grits. They are compared to the gold-bearing series of Nova Scotia and doubtfully referred to the Huronian system.

Hind,[29] in 1878, describes at Mullens Cove, in the Laurentian series of Labrador, a succession of interbedded gneisses, micaceous schists, crystalline limestones, and a bed of calcareous conglomerate. The thickest layer of white crystalline limestone is 35 feet.

Emerson,[30] in 1879, describes the rocks of Frobisher Bay, collected by C. F. Hall, as consisting of granite, gneiss, magnetite gneiss, hornblendic gneiss, mica schist, etc.

Bell,[31] in 1879, reports on explorations of the east coast of Hudson Bay. In this region are large areas of gneisses which are referred to the Laurentian and belts of schists referred to the Huronian. With the Huronian are schist conglomerates and quartzites. At the contact of the Laurentian and Huronian the former consists of a coarse quartz and mica rock, while the first rock which is considered Huronian is a dark-green, highly crystalline hornblende schist. The two formations appear as usual to be conformable. Along Manitounuck Sound is an unaltered stratified series in which no fossils were found and which resemble the Nipigon rocks. These are called the Manitounuck group. They consist mostly of siliceous and argillaceous limestones, sandstones, quartzites, shales, ironstones, amygdaloids, and basalts. At Little Whale River is a quartz conglomerate of great thickness below these rocks. The limestones are found at many localities at the base of the series. They have a cherty concretionary and concentric structure. The quartzites and sandstones come in ascending order. Associated with the quartzites, and overlying them, is a series of cherts and shales. These are surmounted by a great thickness of amygdaloids of various kinds and of diorites of a basaltic character. At Richmond Gulf the base of the section consists of sandstone and conglomerate, above which is limestone in a slightly unconformable position, and all is capped by trap. In one place the trap rests with a slight unconformity upon ferruginous beds. Spathic iron ore, sometimes of considerable thickness, is in places interstratified with the sandstone.

Bell,[32] in 1879, reports on the country between Lake Winnipeg and Hudson Bay. The rocks along the route, with the exception of one Huronian trough, are described as Laurentian gneiss. The Huronian rocks belong in one basin or trough, conforming with the general trend of the Laurentian gneiss and mica schist. Its breadth is about 14 miles and its length 143 miles, giving an area of about 2,000 square miles. A mica schist at Pipestone Lake contains different kinds of pebbles. At Seven-mile Point the rock is a micaceous slate conglomerate, the pebbles of which are chiefly of gray syenite. At the junction of the Laurentian and Huronian the two formations appear as usual to be conformable with each other. The last of the Laurentian series consists of gray, coarse, rough-surfaced quartz and mica rock. The first rock on what is considered to be the Huronian side of the boundary consists of highly crystalline dark-green hornblende schist, ribboned with fine lines of white quartz grains. This schist is interstratified with bands of finely ribboned, slightly calcareous gray gneiss.

Bell,[33] in 1880, reports on explorations of the Churchill and Nelson River and around Gods and Island lakes. The Laurentian gneiss is the prevailing rock throughout the whole district between Knee and Island lakes. The stratification, while moderately distinct, is often banded and contorted. Its average texture is of a medium variety, or rather tending to fine grain, but coarse forms are occasionally seen. There is no prevailing or general direction in the strike of the gneiss. The Huronian rocks occupy a series of troughs in several localities. The rocks are schist conglomerate, sometimes garnetiferous, steatite schists, green schists, and felsite schists, most of them being more or less calcareous. The Laurentian gneiss occupies the area between the Huronian troughs. The strike of the Laurentian gneiss in the neighborhood of the Huronian rocks appears in most cases to correspond with that of the latter.

Bell,[34] in 1881, reports on Hudson Bay and some of the lakes and rivers lying to the west of it. At different points are found various gneisses and schists which are referred respectively to the Laurentian and the Huronian. Hudson Bay as a whole lies in the great Laurentian area of the Dominion. The long chain of islands which fringe the east coast are composed of bedded volcanic and almost unaltered sedimentary rocks, resembling the Nipigon series of Lake Superior, which may be of Lower Cambrian age. On the western side of the bay, from the Churchill River northward, are found quartzites and other rocks which may also belong to the Cambrian system. Cambro-Silurian rocks rest almost horizontally upon the Laurentian along the southwestern side of the bay.

Bell,[35] in 1883, reports upon the geology of the basin of Moose River and adjacent country. The boundaries of the Laurentian and Huronian formations appear to be conformable to each other. Massive granites occur abundantly with the Laurentian gneisses and Huronian schists. The granites generally lie close to the junction of the Huronian and Laurentian, this being the usual position of these granite areas in the great region northward of Lakes Huron and Superior.

Bell,[36] in 1885, describes granite and gneiss at North Head, Button Islands, Ungava Bay, Nunaungok, Ashes Inlet, Nottingham and Digges islands, Stuparts Bay, Eskimo Inlet, Port DeBoucherville, and Port Laperrière. A portion of the west coast of Hudson Bay is occupied with diorites, hornblende schists, and mica schists, which may be referred to the Huronian series. Deadmans Island consists of white and light-gray quartzites and glossy mica schists striking N. 75° W. The whole of the western part of Marble Island consists of white and light-colored quartzite bearing a strong resemblance to white and vein marble. The beds of quartzite are very massive, although their surfaces are often ripple-marked, being sometimes as fine and regular as the fluting on a washboard.

Bell,[37] in 1885, gives a general characterization of the geology of Hudson Bay. The distribution of the Huronian series is intimately connected with that of the Laurentian, being found mostly within the limits of the latter. The rocks of the Huronian system appear to rest conformably upon the Laurentian in all cases observed. About the mouth of Churchill River, on the west side of the bay, and for some miles along the coast, are found massive and thinly bedded quartzites with conglomerate beds, the pebbles being mostly of white quartz, interstratified with occasional thin shaly layers. These strata may form a part of the Huronian series, but they also resemble the gold-bearing rocks of Nova Scotia. On Little Whale River and in Richmond Gulf, on the east side of the bay, another set of rocks is found following the Huronian and underlying unconformably the Nipigon series. This intermediate formation consists of beds of hard red siliceous conglomerate and red and gray sandstones, with some red shales, and appears to have a considerable volume. The Nipigon formation is largely developed along the east main coast of Hudson Bay, between Cape Jones and Cape Dufferin, and consists of compact, nonfossiliferous, bluish-gray limestones, coarse cherty limestone breccias, quartzites, shales, diorites, amygdaloids, and manganiferous clay ironstones. The limestones of Lake Mistassini, in the interior of the Labrador Peninsula, bear a strong resemblance to those of the east main coast.

La Flamme,[38] in 1885, gives geological observations on the Saguenay region. The pre-Cambrian rocks are divided into two series, a gneissic and a labradorite series, which are together included in the Laurentian, although nothing is said as to their structural relations.

Bell,[39] in 1885, reporting on the Labrador coast, describes gneiss and granite at Fords Harbor and Mission station, Nain, at Nachvak Inlet, at Skynners Cove, and at other points. The granite sometimes becomes syenitic and the gneiss is sometimes well laminated.

Boas,[40] in 1885, describes the nucleus of Baffin Land as everywhere consisting of gneiss and granite.

Greely,[41] in 1886, finds toward the head of Chandler Fiord high cliffs of schist and slate, and in Ruggles River, at the outlet of Lake Hazen, large slabs of slate.

Low,[42] in 1886, reports on the Mistassini expedition. The Laurentian gneisses and associated rocks occupy the whole country from the Gulf of St. Lawrence to James Bay, along the route traversed, with the exception of some areas of Huronian and Cambrian in the vicinity of Lake Mistassini. The Laurentian rocks include gneiss, hornblende schists, mica schists, crystalline limestones, and areas of triclinic feldspar rocks. The rocks described by Richardson, north of Lake Abatagomau, are similar to the epidotic and chloritic slates of the Shickshock Mountains and the Eastern Townships and are referred to the Huronian.

Bell,[39] in 1886, gives additional observations on the geology of Hudson Bay. From Eskimo Point to the entrance of Chesterfield Inlet, a distance of 180 miles, the rock specimens embrace hornblende schists, greenstones, sandstone altered to quartzite and holding fragments of indurated shale, white quartz rock, quartzite like that of Marble Island felsite, crystalline hornblende rock, diorite, chert, mica schist, porphyry, granulite, red jasper, chloritic schists, etc. The majority of the lithological specimens correspond with the rocks of the Huronian series; Laurentian types are absent, and the probabilities are that Huronian rocks prevail all along the northwest coast of Hudson Bay, from Eskimo Point to Chesterfield Inlet, and again at Repulse Bay. The widely extended areas of massive granitoid character about Hudson Bay are regarded as Primitive gneiss, and are, there is little doubt, more ancient than the regularly stratified gneisses which prevail in the Ottawa Valley. The Huronian rocks of the region are unlike those on the north shore of Lake Huron, consisting of massive diorites, argillaceous and dioritic slate conglomerates, granite syenites, schistose and jaspery iron ores, limestones, dolomites, and imperfect gneisses, with a great variety of schists. The Manitounuk series is largely made up of rocks of volcanic origin.

Bell,[43] in 1887, reports on explorations of portions of Attawapiskat and Albany rivers. Various granites, gneisses, and schists are found at Pelican Lake, Lake St. Joseph, the upper sections of Albany and Boulder rivers, and Lake Lansdowne. At Lake St. Joseph a conglomerate is found. The granites and gneisses are placed with the Laurentian and the schists and conglomerates with the Huronian.

Dawson,[44] in 1887, as a result of an exhaustive review of the literature of northern Canada, states that Archean or Eozoic rocks are dominant in the northern part of the continent. They also form the greater part of Greenland, and doubtless underlie at no great depth the entire Arctic archipelago. While the information available is sufficient to indicate the existence of the different subdivisions of the Archean which are met with in the southern portion of Canada, including the lowest Laurentian or granitoid gneiss series, the Middle Laurentian, possibly the peculiar rocks classed as the "Upper Laurentian," and certain of the more schistose and generally darker colored and more basic rocks classed as Huronian, it is far too imperfect to admit of the separation of these subdivisions on the map. It is evident that the Huronian is represented in parts of the west coast of Greenland, and it is probably also recognizable on the Labrador coast and on the west coast of Hudson Bay. The occurrence of well-stratified gneisses with mica schists and crystalline limestones, with associated graphite and magnetite, appears to indicate the presence of Middle Laurentian. These rocks occur on the southern part of Baffin Land, Frobisher Bay, Cumberland Sound, and Melville Peninsula. The term Cambrian is made to include all rocks above the Huronian to the base of the Cambro-Silurian. Extensive areas placed in the Cambrian on the Arctic coast and in the vicinity of Coppermine River are analogous in character to those of the Keweenaw or Animikie of the Lake Superior region, and probably represent both groups of that great copper-bearing series. Throughout the northern part of the continent the characteristic Cambrian formation, composed largely of volcanic rocks, apparently occupies an unconformable position with regard to the underlying Laurentian and Huronian systems. The present remnants show that these rocks have undergone comparatively little subsequent disturbance. The Cape Rawson beds of Grinnell Land are provisionally referred to the Cambrian, on account of their lithological resemblance to the rocks of the Animikie, and also on account of their similarity to the Nova Scotia gold-bearing series.

In the above summary, as the terms are used in this volume by Dawson, the Middle Laurentian, much of the Huronian, and the Coppermine and equivalent series, which are placed in the Cambrian, are to be included in the Algonkian; while the Lower Laurentian is largely or wholly Archean.

Packard,[45] in 1888, describes syenitic and gneissic rocks of the Laurentian formation at various points, among which are Sleupe Harbor in Gore Island near Shallop, the bay east of Anse-au-Loup, Caribou Island, Cape St. Francis, and Square Island.

McConnell,[46] in 1890, mentions granite gneisses east of the Rocky Mountains at the rapids of Slave River and Fort Rae. These evidently belong to the Laurentian or the oldest division of the Archean. West of the Rocky Mountains crystalline schists are largely developed along the valley of the Pelly-Yukon, occurring in numerous exposures from the international boundary to Fort Selkirk, and they continue up the Lewes about 30 miles. This belt of crystalline rocks has a width of somewhat more than a hundred miles. The eastern edge of the area consists largely of quartzose schists, chlorite schists, mica schists, diabases, and serpentines, which are occasionally interbedded with bands of slate and limestone, and are broken in many places by igneous intrusions. The green schists, in ascending the river, are underlain by foliated mica gneisses alternating with hornblende gneisses, which are distinctly Archean in appearance and in lithological character.

McConnell,[47] in 1893, reports a small area of Archean gneisses on the northern shore and neighboring islands of Lake Athabasca, on the islands of Lake Mammawi, and in the tilted deposits bordering Quatre Fourches River. The gneisses include hornblendic, micaceous, chloritic, and epidotic varieties. In places they pass into a mica schist or chlorite schist. The gneisses strike N. 10° to 20° W.

Dowling,[48] in 1896, reports on the geology of the country in the vicinity of Red Lake and part of the basin of Berens River, in the district of Keewatin, Canada. The rocks exposed are all Archean, including gneisses and granites classed as Laurentian, and folded schists and greenstones classed as Huronian.

The Laurentian rocks prevail over a much greater area than the Huronian rocks, being seen along White and Berens rivers, on Lac Seul, and on English and Matawan rivers. They are gneisses and granites, the latter in places apparently intrusive in the former, as along the headwaters of Berens River. The granites are occasionally intrusive also in the Huronian to the south.

The Huronian rocks are a series of schists, limestones, and water-deposited volcanic materials. They occur in two main areas. The eastern one is in the vicinity of Clearwater and Woman lakes. The eastern boundary of this area has not been defined; to the west the Huronian is in contact with the Laurentian. From the southwestern part of the area a belt extends southwest to the vicinity of Shallow Lake. The western area of Huronian occurs in the vicinity of Red Lake, and is surrounded by and incloses areas of Laurentian granite and gneiss.

Contacts of the Laurentian and Huronian rocks are described for numerous localities. The contacts are "generally of a brecciated character, the gneisses and granites while in a plastic condition surrounding and inclosing the Huronian schists."

The Huronian rocks are similar in many respects to the Keewatin series of the Lake of the Woods and Rainy Lake districts, to the south; but the Huronian of the area under discussion includes dark-blue limestone and conglomerates with jasper pebbles, both very similar to those of the typical Huronian area north of Lake Huron, and the rocks are accordingly mapped as Huronian.

The Coutchiching, supposed by Lawson to underlie the Keewatin of the Rainy Lake country, is possibly here represented by a small area west of Shallow Lake, mapped as Huronian. However, at Gull Rock Lake, rocks which still more resemble the Coutchiching of the Rainy Lake region are found to be but highly altered Huronian beds in contact with the Laurentian, which, when followed along the strike, take on the general aspect of the remainder of the Huronian of the district.

Low,[40] in 1897, reports on his explorations of the Labrador Peninsula, along the East Main, Koksoak, Hamilton, Manicuagan, and portions of other rivers. Laurentian rocks occupy nine-tenths of the area of the peninsula. They include gneisses and schists, some of clastic origin, some of eruptive origin. The clastic portion is in nearly all cases the oldest.

The Huronian rocks comprise beds of arkose, conglomerate, limestone, shale, slate, sandstone, chert, quartzite, mica schist, and eruptives, in part at least contemporaneous with, and at present represented by, schists characterized by chlorite, epidote, altered hornblende, hornblende, sericite, and hydromica; also diabase, diorites, and various granites. They occur in two large areas and several small ones. One of the large areas is along East Main River, from near the mouth inland for 160 miles, and the other is in the vicinity of the large lakes southwest of Lake Mistassini.

The Laurentian and Huronian rocks are overlain, with strong unconformity, by a series of rocks classified as Cambrian, comprising arkose, sandstone, limestone, dolomite, felsitic shale, argillite, and argillaceous shale, together with gabbro, diabase, fine-grained decomposed traps, and volcanic agglomerates. The fine-grained traps are interbedded with the clastic rock. No acidic eruptives appear. On the east coast of Hudson Bay and at Chateau Bay, near the eastern entrance of the Strait of Belle Isle, some of the traps have formed overflows on the surface and are now represented by dark-green, fine-grained melaphyres having large amygdaloidal cavities filled with quartz and agate. No fossils have been found in these supposed Cambrian rocks and their precise age and equivalency can only be conjectured. However, the mode of occurrence of thick beds of magnetic iron ore overlain by cherty, nonfragmental carbonates in this series closely resembles that of the iron ores of the Lake Superior region described by Irving, Van Hise, and others. This, with other characters of resemblance, renders it almost certain that the two developments represent the same period, or, in other words, that the Animikie rocks of Lake Superior, assumed to be Lower Cambrian, are equivalent to the rocks here described as Cambrian in Labrador.

Tyrrell and Dowling,[50] in 1897, report on the country between Athabaska Lake and Churchill River in Canada. The area covered by the report is bounded on the south by Churchill and Clearwater rivers; on the west by the lower portion of Athabaska River; on the north by Athabaska Lake, Stone River, with its expansions, Black and Hatchet lakes, Wollaston Lake, and Cochrane or Ice River; on the east by the lower part of Cochrane River, Reindeer Lake, and Reindeer River.

Laurentian rocks, including hornblende granites, biotite granites, muscovite granites, granitoid gneisses, gabbros, and norites, are found outcropping on Churchhill River from 2 miles below the mouth of Mudjatick River eastward to the mouth of Reindeer River; thence northward they occupy most of the eastern part of the district. Farther west they are followed north to Cree Lake. In the northern part of the area they occupy most of the northern shores of Athabaska and Black lakes.

As far as at present known, the Huronian is represented in this district solely by three small areas on the north shore of Lake Athabaska. The Huronian here includes quartzites, calcareous sandstones and schists, conglomerate, hälleflinta, ferruginous chlorite schists, and other green schists.

The Laurentian and Huronian are unconformably overlain by horizontal sandstones and conglomerates, called the Athabaska sandstone, which is placed in the Cambrian. However, these sandstones are similar to the sandstones found to the north associated with quartz porphyries, diabases, etc., like those of the Keweenawan of Lake Superior, and there is little doubt that the two sets of rocks belong to the same horizon.

Low,[51] in 1898, reports on a traverse of the northern part of the Labrador Peninsula, from Richmond Gulf to Ungava Bay. Laurentian rocks occupy the greater part of the area. These are chiefly granites, more or less foliated. They are of different ages, but, except in a few cases, they can not be discriminated. Cutting them are intrusive diabases.

Intimately associated with the granites is a series of more or less quartzose mica gneisses and mica schists, interbanded with hornblende schists and hornblende gneisses, and at times with quartz magnetite gneiss. These gneisses and schists are supposed to represent a bedded series of rocks somewhat similar to the Grenville series. While most of the schists are thus probably very ancient, others may be of the same age as the so-called Cambrian.

So-called Cambrian rocks were met with along the east coast of Hudson Bay, to the north of Cape Johns, and on Larch River from its junction with the Kaniapiskau upward for 30 miles. A section examined on the east side of Castle Peninsula, on the north side of the outlet of Richmond Gulf, presents rocks closely resembling the Mesnard quartzites and the Kona dolomites of the Lower Marquette series of the south shore of Lake Superior, capped by a later outflow of trap, classed as Algonkian by Van Hise.

Tyrrell,[52] in 1898, reports on an exploration of Doobaunt, Kazan, and Ferguson rivers northwest of Hudson Bay, the northwest coast of Hudson Bay, and on two overland routes from Hudson Bay to Lake Winnipeg.

Laurentian rocks, including granites, diorites, and granite and diorite gneisses, occupy a large part of the region crossed by the three main lines of travel—Doobaunt River and Chesterfield Inlet, Kazan and Ferguson rivers, and the west coast of Hudson Bay—although their precise extent is unknown.

The Huronian rocks include three more or less distinct groups—the Marble Island quartzites, the greenish quartzites and graywackes, and the more or less highly altered and often schistose diabases and gabbros. The largest area of Huronian is found along the coast of Hudson Bay from Bakers Foreland south to a point 45 miles north of Cape Esquimaux, and inland for 70 miles up the Ferguson River. Other areas are found between Schultz and Baker lakes, near Lake Angikuni, near Kasba and Ennaidäi lakes, on the north shore of Doobaunt Lake, and on the east shore of Wharton Lake.

The Huronian rocks are overlain unconformably by the Athabaska sandstone. As this sandstone is older than the flat-lying Cambro-Silurian limestone and is unconformably above the Huronian, it is assigned to the Cambrian, although no fossils were found in the formation. Lithologically the whole terrane presents a remarkable resemblance to the red sandstones and Cambrian quartz porphyries of the Keweenawan rocks of Lake Superior, and the two terranes are regarded as holding essentially similar positions in the geological time scale.

PARKS,[53] in 1900, describes the geology of the Moose River basin in Canada, including Moose and Abitibi rivers, tributary to James Bay. This is an immense triangular area, of which the apex is at James Bay and the base stretches from above Lake Abitibi to a point west of Kabinakagami. The southern and major portion of this triangular area consists of Laurentian gneisses and granites crossed by bands of Huronian rocks. The term "Huronian" is applied to all the rocks above the Laurentian and beneath the lowest fossiliferous strata, in this sense including rocks of various ages and different petrographic nature, such as Logan's original Huronian, Lawson's Keewatin and Coutchiching series, the Animikie and Nepigon formations, the graywacke and associated rocks of the Sudbury region, and the various schists, altered eruptives, and crushed granites characteristic of wide areas in northern Ontario. In the region under discussion the Huronian is represented by a great variety of schists, presumably of clastic origin, and by others of altered eruptive nature, closely associated with both acidic and basic eruptives in various stages of decomposition. The discussion of the distribution of the Huronian rocks is summarized from reports of the Ontario Bureau of Mines, the Canadian Geological Survey, and the Canadian Government.

LOW,[54] in 1901, describes and maps the geology of the south coast of Hudson Strait and the west and south shores of Ungava Bay. Granite and gneiss of various ages occupy three-fourths of the coastal area. Associated with them are gabbros, diabases, and other greenstones, cherts, quartzites, shales, and slates. All are provisionally referred to the Archean.[a] Flat-bedded Cambrian rocks, so called, rest with apparent unconformity upon the crystalline complex.

TYRRELL and DOWLING,[55] in 1901, describe and map the east shore of Lake Winnipeg. The rocks are all Archean and the great preponderance of gneisses and granites of the Laurentian is the chief feature.

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[a] Pre-Cambrian.

Small areas of Huronian greenstones and schists occur in two localities—one on Lac du Bonnet and the other at the mouth of Wannipegow River.

In an account of a trip from Edmonton through Yellow Dog Pass, in the Rocky Mountains, to Canoe River, a tributary of Columbia River, McEvoy[a] describes and maps Shuswap rocks, of Archean[b] age, occurring on Mica Mountain, near the western end of the route. The series includes dark, glittering mica schists; easily weathering, thinly foliated, garnetiferous mica schist, with a high percentage of mica and garnet; hard, garnetiferous mica schist in massive beds; bands of dark, fine-grained micaceous rock apparently of eruptive origin, and layers of fine-grained gneiss, which, in some instances at least, is certainly intrusive. The whole series, while differing somewhat from the Shuswap series of the southern interior of British Columbia, shows the main characteristics of that series and may be classed as such. The age of this series as given by Dawson is Archean.

Bell,[56] in 1901, describes and maps the geology of Baffin Land, or northern shore of Hudson Strait, as the result of his work of 1897.

The rocks of the northern side of Hudson Strait from North Bay to Chorkback Inlet and inland to Lake Mingo consist of well-stratified hornblende and mica gneiss, mostly gray in color, but sometimes reddish, interstratified with great bands of crystalline limestones, parallel to one another and conformable to the strike of the gneiss, which in a general way may be said to be parallel to the coast in the above distance. The direction, however, varies somewhat in different sections of the coast. All are of Laurentian age.

The distinguishing feature in the geology of the southern part of Baffin Land is the great abundance, thickness, and regularity of the limestones associated with the gneisses. At least ten immense bands were recognized, and it is probable that two others, discovered in North Bay, are distinct from any of these. There would, therefore, appear to be twelve principal bands as far as known, to say nothing of numerous minor ones, between Icy Cape and Chorkback Inlet. Their total thicknesses may be 30,000 feet, or an average of 2,500 feet for each of the principal bands. These rocks are correlated with the Grenville.

Johnston,[57] in 1902, gives a brief preliminary account of the Laurentian and Huronian rocks of the eastern part of the Abitibi region.

Wilson,[58] in 1902, gives a brief preliminary account of the Laurentian and Huronian rocks of the western part of the Abitibi region.

Dowling,[59] in 1902, gives a brief preliminary account of an examination of the west coast of Hudson Bay. Animikie sediments and traps appear at Sutton Mill Lake. The jasper portions of the

[a] Ann. Rept. Geol. Survey Canada for 1898, new series, vol. 11, 1901, pp. 5 D–44 D, with sketch map.

[b] Pre-Cambrian.

series contain minute oval and rounded concretions so characteristic of the iron formation of the Animikie.

Wilson,[60] in 1903, makes a geological reconnaissance about Albany River. Laurentian and Huronian rocks are found. The latter are similar to Lawson's Keewatin series. The broadest belt of these rocks was crossed about 38 miles (by water) above Lac Seul, and extends for a distance of about 20 miles. A second narrow belt is crossed at the Height-of-Land portage leading into Big Portage Lake from the waters tributary to the Wenassaga.

Low,[61] in 1903, describes the geology of the Nastapoka Islands, Hudson Bay. The rocks forming the islands are as follows, in descending order:

Section of rocks forming Nastapoka Islands, Hudson Bay.

1. Rusty-weathering, dark-gray siliceous rock containing ankerite (carbonate of iron and magnesia) and magnetite	20–100
2. Dark-gray siliceous rock containing magnetite with small quantities of ankerite	50–250
3. Red jaspilite rich in hematite ore	10–100
4. Red jaspilite poor in hematite ore	5–20
5. Purple, or greenish-weathering, dark-green graywacke shales	10–70
6. Red jaspilite poor in hematite ore	0–5
7. Light greenish-gray sandstone and shale	10–300
8. Fine-grained dolomite	0–50

There is a general dip toward the west, or toward the sea, of 5° to 15°. There are north-south faults, the upthrow being almost on the west side, with the result that the rocks appear in north-south ridges. The displacement is small and rarely exceeds 100 feet. Another system of faults lies transverse to the first system.

Large areas of similar unaltered sedimentary rocks occur throughout the peninsula of Labrador, and are probably the equivalents of certain of the iron-bearing series above Lake Superior and of those to the west of Hudson Bay, hand specimens from these localities being undistinguishable. On former maps of portions of the peninsula of Labrador the areas of rocks belonging to this formation have been colored as belonging to the Cambrian formation, and in the earlier reports on this region the rocks were thought to be a part of that system, owing to their unaltered condition, in contrast with all the other rocks of that vast area, which were either crystalline granites and other irrupted rocks or crystalline schists and gneisses, so completely metamorphosed as to have lost all trace of their original sedimentary nature, if any were sediments. These highly crystalline rocks were classed as Laurentian or Huronian and were considered to be much older than the unaltered rocks of the so-called Cambrian areas. More extended and closer study of both the unaltered and the crystalline rocks and of their relations to one another has changed the views of the writer, and he now considers the unaltered, so-called Cambrian rocks to be the equivalents of many of the gneisses and schists classed as Laurentian (Grenville series), and the Huronian areas of the Labrador Peninsula to represent a portion of the unaltered rocks and their associated basic eruptives (traps, trap ash, etc.) altered by the irruption of granite and rendered schistose by pressure. The granites which have been classed as typical Laurentian always cut and alter the bedded rocks wherever seen in direct contact with them, and are consequently newer than the latter.

During the last season (1899) very thin layers of carbon with some resemblance to organic forms were found in the sandstones of Cotter Island; these have the appearance of lowly organized plant life, lower than the known fossils from the lowest beds of the Cambrian, and consequently this formation is older than the Cambrian. It is proposed, therefore, to class these so-called Cambrian unaltered rocks as Laurentian, as they represent the oldest known sedimentary rocks in northeastern America and probably in the world.

Low,[62] in 1903, describes and maps the geology of the east coast of Hudson Bay. All the rocks except those which form the chains of islands along shore between Portland Promontory and Cape Jones, and also a narrow margin on part of the coast in the same region, have been cut by granite, which has not only intimately penetrated them but by its heat and pressure has so changed them to crystalline schists and gneisses that only in a few places can any trace of an original sedimentary origin be found. The unaltered sedimentary rocks with their associated sheets of trap and diabase bear a remarkably close resemblance not only to the so-called Cambrian rocks of other parts of the Labrador Peninsula but also to the iron-bearing rocks of the southern shores of Lake Superior and the Animikie and Nipigon rocks to the north of Lake Superior. In all likelihood they are of pre-Cambrian age and, in the opinion of the writer, are the oldest known sedimentary rocks of Canada. Notwithstanding this opinion they will continue to be classed as Cambrian in order to correspond with the areas of similar rocks of Labrador which have already been so classed. The series comprises, from the base up: Coarse arkose, banded arkose, sandstone, and graywacke, chert impregnated with oxide of iron and red jasper, cherty carbonate, carbonaceous shales, and sandstone. Included in this series are sheets or laccoliths of dark-green trap. This rock also flowed out to the surface. The basement rock from which this series is derived has not been recognized in the region under discussion.

Bell,[63] in 1903, describes and maps the geology of the basin of Nottaway River. Granites and gneisses referred to the Laurentian occupy the larger portion of the area. They are for the most part intrusive into the crystalline schists referred to the Huronian. Huronian rocks occur principally in a large area near the center of the region and in small areas north of the center of the region and south of Lake Mistassini in the eastern part. The large tract of Huronian rocks forms a part of the great belt of Huronian rocks extending continuously from the eastern side of Lake Superior to Lake Mistassini, a distance of 700 miles. The Huronian may be grouped in three classes, namely, (1) crystalline schists, together with some other rocks forming a comparatively small proportion of the same series, (2) massive greenstones, and (3) granites. The schists embrace a considerable variety, but the greater part of them are dark-green hornblendic or dioritic, and they often pass into more or less massive greenstones, so that it becomes difficult to map the two varieties separately. Dolomite, quartzite, arkose, conglomerate, and agglomerate are exceptional occurrences.

Tyrrell and Dowling,[64] in 1903, report on the northeastern portion of the district of Saskatchewan and adjacent parts of the districts of Athabaska and Keewatin, comprising an area adjacent to the north end of Lake Winnipeg. The east, northeast, and northern portions of the area mapped are occupied by Laurentian and Huronian rocks, the Laurentian rocks being in the larger areas. They consist of granites and gneisses, some of which are intrusive into the Huronian and some of which are probably basal to it. Huronian rocks are found in small areas at Cross Lake and at Pipe Lake and in a large area extending from Wekusko Lake to Athapapuskow Lake. They consist of conglomerates, quartzites, basic eruptives and greenstones, and altered schists, similar to rocks of Lawson's Keewatin and Coutchiching series.

Bell,[65] in 1904, describes the Laurentian and Huronian rocks of the Moose River basin. The former include acidic igneous rocks; the latter, greenstones, green schists, and certain sediments, with doubtful relations to one another and to the Laurentian.

Wilson,[66] in 1904, reports on Nagagami River and other branches of the Kenogami. Numerous exposures of Archean rocks are described, but the general geology is not summarized. An interesting feature is the occurrence in this area of Silurian limestones.

McInnes,[67] in 1904, reports on a geological reconnaissance along Winisk River, Keewatin district. The nature and distribution of the Laurentian and Huronian rocks crossed by the river are described. At a point 26 miles from Hudson Bay on the river an anticline brings up a series of quartzites and slates underlying unconformably the Silurian rocks of this area. The trend of the anticline would carry it eastward to Sutton Mill Lake, where rocks of the Nastapoka series were noted by Dowling in 1901, and it seems not unlikely that these

Winisk beds may belong to the same series. They have been classed as Animikie.

WILSON,[68] in 1905, reports on Little Current and Drowning rivers, branches of the Albany, east of Lake Nipigon, and notes the existence of granitic and gneissic and green schistose rocks at many points. A considerable mass of Silurian limestone is found along Pagwachuan River.

MCINNIS,[69] in 1905, reports on the upper parts of Winisk and Attawapiskat rivers. Archean biotite gneisses, varying but slightly in composition and always well foliated, are the prevailing rocks. They are much disturbed by the intrusion of coarse white granite or pegmatite. Two belts of Keewatin, made up for the most part of massive diorite and diabase and chloritic and feldspathic schists, were noted, one occupying the valley of Kawinogans River for a distance of about 25 miles, and the other being an irregularly shaped area immediately south of Nibinamik Lake on Winisk River.

CAMSELL,[70] in 1905, reports on the country around the headwaters of Severn River. The whole area is occupied by Archean granites and gneisses with a few bands of dark basic rocks called Huronian.

SUMMARY OF PRESENT KNOWLEDGE.

A great area of pre-Cambrian rocks, frequently called the pre-Cambrian shield of North America, extends from the Great Lakes and St. Lawrence River northwest, north, and northeast to the Arctic Ocean, Hudson Bay, and Atlantic Ocean—a larger area than all the remaining pre-Cambrian areas of North America combined. Portions of the pre-Cambrian shield adjacent to the Great Lakes and to St. Lawrence River have been separately considered under the headings Lake Superior region, original Huronian region, original Laurentian region, etc., because they have been studied in some detail. Under the heading Great Northern region are treated all of the pre-Cambrian shield not already covered.

The Great Northern region is not yet penetrated by railways and is almost uninhabited. Exploration has consisted for the most part in following canoe routes, and because of the difficulties of travel, great distances, and short summers, even such exploration has had to be hurriedly done. Hence it is that the geological study of this region has been merely reconnaissance along canoe routes. The account of this reconnaissance appears for the most part in the reports of the Canadian Geological Survey and the Ontario Bureau of Mines.

A granite gneiss complex, mapped by the Canadian geologists as "Laurentian," occupies much the largest part of this vast region. So far as can be ascertained from the reconnaissance reports, this complex is in all essential respects like that described as occurring in the original Huronian, original Laurentian, and Lake Superior areas. All the varieties of rocks found in these areas occur here. It appears probable that the orthoclase gneiss, which is the predominant rock in the original Laurentian district, also predominates in the vast northern region.

At many places within the expanse of Archean are relatively small belts mapped as "Huronian" on the Canadian maps. These consist of much-altered sedimentary rocks, such as quartzite, graywacke, conglomerate, limestone, etc., and of igneous greenstones and granites and a variety of crystalline schists, hornblendic, micaceous, and chloritic, most of them undoubtedly derived from the alteration of sediments and igneous rocks. Similar assemblages of rocks in the Lake Superior region have been found to belong to four great divisions separated by unconformities and referred to the Keewatin, lower Huronian, middle Huronian, and upper Huronian. The so-called "Laurentian" granites and gneisses are in large part intrusive into the "Huronian," but it is apparent that the term "Laurentian" covers granites of different ages, varying from as old as the Archean to late Huronian. Indeed, so far as the pre-Keweenawan series are concerned, the past classifications of the rocks of the Great Northern region into "Laurentian" and "Huronian" means simply a lithological division between light-colored rocks such as granites and gneisses on the one hand and gray and green sediments and greenstones on the other hand. This classification does not signify structural or age relations beyond the fact that the rocks are older than the Keweenawan and usually the Animikie.

Overlying the rocks mapped as "Laurentian" and "Huronian" in several areas are so-called "Cambrian" sediments, distinguished from the rocks called "Huronian" by their less altered and less folded condition and by association with fewer intrusives. Some of these series of rocks are similar to the upper Huronian, while others are very like the Keweenawan rocks of the Lake Superior region.

For the most part it is impossible to give any definite lithological or structural account of the numerous districts in which "Laurentian," "Huronian," and "Cambrian" rocks have been mentioned as occurring, but a few of the principal features may be noted. In so doing it will be necessary to use the terms "Laurentian," "Huronian," and "Cambrian" with the broad significance given them on the Canadian maps.

Bell emphasizes as the distinguishing feature of the geology in the southern part of Baffin Land the great abundance, thickness, and regularity of limestones associated with gneisses, which he correlates with the Grenville series.

According to Low, the central part of the Labrador Peninsula is very largely occupied by "Laurentian" rocks, with "Huronian" rocks consisting of altered sediments and basic and acidic igneous rocks in subordinate quantity. In the northern part of the peninsula are schists and gneisses, supposedly representing a bedded series similar to the Grenville series.

On the east coast of Hudson Bay and in various parts of Labrador is a series of comparatively unaltered sediments containing beds of magnetic iron ore. In the past these have been supposed to be above the "Huronian" and "Laurentian" rocks of this area, and accordingly have been mapped as "Cambrian" and correlated with the Animikie of the Lake Superior region. Low now concludes that these rocks are but less metamorphosed phases of the "Huronian" or "Laurentian" rocks and are to be equated with the iron-bearing series to the west of Hudson Bay and with certain of the iron-bearing series of the Lake Superior region, the superior position of the rocks on the shore of Hudson Bay being explained by faulting. He had previously called attention to the similarity of the succession on Richmond Gulf, on the east side of Hudson Bay, to the Mesnard quartzite and Kona dolomite of the lower Huronian of the Marquette district, of the Lake Superior region. He also reports the discovery of certain obscure forms possibly representing life forms lower than the Cambrian. From Low's descriptions and photographs it is thought that the iron-bearing series of the east coast of Hudson Bay corresponds more closely to the Animikie or upper Huronian of the Lake Superior region than to the lower iron-bearing series of the Lake Superior region. In various areas about Hudson Bay fragmental rocks, such as sandstone, quartzite, shale, slate, slate conglomerate, and limestone, occur. These are associated with imperfect gneisses, a great variety of schists, and schistose and jaspery iron ores. According to Bell, above these rocks at Little Whale River and at Richmond Gulf are formations consisting of beds of siliceous conglomerate and red and gray sandstone, with some red shales. Unconformably overlying this intermediate group is the Manitounuck group, which consists of argillaceous and siliceous limestones, sandstones, quartzites, shales, amygdaloids, basalts, and clay ironstones. On the Coppermine River and at Doobaunt Lake occur traps, amygdaloids, and porphyries, associated with sandstones and conglomerates, constituting a series which is lithologically similar to the Keweenawan of Lake Superior.

To the south of Hudson Bay the preponderance of "Laurentian" rocks is the same as elsewhere in this region. The "Huronian" rocks present the same features as those of the Lake Superior and Huron districts to the south.

To the west and southwest of Hudson Bay the "Laurentian" are again in much larger area than the "Huronian" rocks. A series similar to the Keweenawan copper-bearing series of the Lake Superior region, called the Athabaska sandstone and mapped as "Cambrian," has been reported by Tyrrell, Dowling, and McConnell as overlying the "Laurentian" and "Huronian" rocks near Athabaska Lake, and westward from Baker Lake, which lies to the west of Chesterfield Inlet. "Cambrian" rocks have also been reported both northwest and southeast from north of Nelson River on the southwest side of Hudson Bay and east of Great Bear and Great Slave lakes.

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CHAPTER IX.

NEW ENGLAND.

SECTION 1. MAINE.

SUMMARY OF LITERATURE.

JACKSON,[1] in 1837, observed granite, gneiss, and mica schist at many localities. At one place schistose fragments occur in syenite, which indicates that the syenite has been thrown up in a melted state since the deposition and induration of the argillaceous and talcose slates included. Dikes very frequently cut the fossiliferous horizon.

HITCHCOCK (EDWARD),[2] in 1837, describes a rock succession at Portland as consisting from the base upward of (1) granite; (2) gneiss; (3) talcose and mica slates, with quartz rock; (4) hornblende slate; (5) limestone; (6) plumbaceous mica slate; (7) pyritiferous mica slate. The latter has the aspect of a graywacke conglomerate, being filled with distinct rounded masses of quartz rock. It is really a mica slate conglomerate. The series is in a vertical position and the whole is cut by greenstone dikes.

JACKSON,[3] in 1839, includes in the Primary rocks of Maine the granites, gneiss, talcose slate, and argillaceous slate. The Transition rocks are a great formation, which includes slates, limestones, fine graywackes, and coarse conglomerates. It is also fossiliferous. At one place mica slate is thrown aside by intrusive granite.

HITCHCOCK (C. H.),[4] in 1861, divides the unfossiliferous rocks into Stratified or Azoic and Laurentian. With the latter are placed granitic, trappean, and Archean rocks. The Azoic rocks, which may be in age Laurentian to Carboniferous, include gneiss, mica schist, quartz rock and conglomerate, jasper, siliceous slate, and hornstone. The quartz rocks and conglomerates are associated. At one place a conglomerate has elongated pebbles that indent each other, which is evidence that they must have been in a plastic condition. Metamorphism may even produce granite and gneiss by aqueo-igneous fusion. The syenites containing fragments of schist and trap, described by Jackson, are believed to be metamorphosed conglomerates, the included pebbles of which have preserved their original shapes. The foliation of the metamorphic rocks generally corresponds with the planes of stratification, but may cross the strata like cleavage planes. The trap dikes are believed to be eruptive.

Hitchcock (C. H.),[5] in 1862, describes the rocks of the southern part of the State as granite and syenite, gneiss and mica schist, saccharoidal Azoic limestone, quartz rock (Taconic), eolian limestone, etc. Presumably the granite and syenite, gneiss and mica schist, and Azoic limestone are Primitive. In the Kennebec Valley are found interstratified limestones and slates, the cleavage of which is almost transverse to the bedding, so that it is possible to get at the true direction of lamination only by following the limestone belts. At one place is an abrupt change from mica schist to granite. A red conglomerate rests unconformably upon a slate at Woodstock.

Hitchcock (C. H.),[6] in 1874, describes three groups of rocks at Portland, the oldest of which is the Huronian. In this system are green talcose schists, hornblendic schist, micaceous and plumbaceous schist, and other varieties. They are referred to the Huronian on the ground that such rocks are typical of this period and that continuity of mineral character indicates similarity of age till otherwise proved.

Huntington,[7] in 1878, describes the region about the headwaters of Androscoggin River. The rocks are classified as Laurentian, Huronian, and Paleozoic. In the Laurentian is gneiss containing limestone. In the Huronian are White Mountain gneisses and schists, mica schists with staurolite, chloritic and whitish argillitic mica schists, sandstone schists, diabase, diorite with serpentine, argillitic mica schists with staurolite, and Rangely conglomerates. In the Rangely conglomerate, when freshly broken, every portion of it except the pebbles resembles in all respects the staurolitic schist. Crossing the strata are belts in which the pebbles are wanting, or have been so changed that they are not apparent, although locally the fragments of the conglomerate are a foot in diameter. Granite, diorite, and felsite are placed among the eruptive rocks.

SECTION 2. NEW HAMPSHIRE.

SUMMARY OF LITERATURE.

Jackson,[8] in 1841, in a general consideration of the geology of the State, says that granite is an igneous rock and is the foundation on which all the more recent formations rest. When it is found cutting other rocks the intense heat has often metamorphosed the adjacent rocks for considerable distances. Reposing directly on the granite is found gneiss, the origin of which is undetermined. By some geologists gneiss is considered a metamorphic rock; others suppose that its stratified structure is due to the crystallization in laminæ and that it is merely the upper crust of granite. Above the gneiss are found mica slate, chlorite slate, and argillaceous slate, which are regarded as metamorphic rocks. Slates and granite alternate with each other, and this is due to the subsequent intrusion of granite. There have been several periods of eruption of trap dikes, as is shown by the manner in which they cut one another.

JACKSON,[9] in 1844, gives many facts as to the distribution of the rocks, with numerous sectional profiles. Granite, syenite, porphyry, trap, basalt, and lava are regarded as eruptive rocks. As a result of outbursts and elevations the strata have been broken up, altered in position, and included between masses of molten gneiss and granite. In this way is explained the intercalation of masses of argillaceous slates in the Primary series and the metamorphism of the sedimentary deposits by igneous action.

ROGERS (H. D. and W. B.),[10] in 1846, state that the assumption that the White Mountains belong to the Primary series involves two errors: First, in assigning all the rocks to the gneissoid class; and, second, in supposing that none of the strata contain organic remains. The gorge of the Saco was closely examined. The rocks were found to have a stratified structure throughout, although in many cases approaching very close to granite. They are regarded as very highly metamorphic sandstones and slates. Associated with the crystalline rocks are semicrystalline sandstones which contain distinct fragments. In a shale are found fossils which lead to the conclusion that the series represents the Levant or Matinal. The metamorphic beds are cut by beds and veins of syenitic granite, and the extremely crystalline character of the slates and sandstones is regarded as due to the igneous material.

JACKSON,[11] in 1848, maintains that in the White Mountains are numerous localities where the granite contains fragments of slate which are not altered by heat beyond mere induration. In New Hampshire numerous masses of older Silurian strata occur intercalated with the Primary rocks.

HITCHCOCK (C. H.) and HUNTINGTON,[12] in 1877, give a full account of the geology of New Hampshire. Hitchcock divides the pre-Paleozoic rocks of northeastern United States into two divisions: First, the more ancient gneisses and granites; second, the area of hydromicaceous and micaceous schists, which are termed Huronian. In the Paleozoic are placed great expanses of clay slates. The first division is divided into four parts: First and oldest, the Laurentian; second, the porphyritic gneiss and the various undetermined granites; third, the Atlantic, and fourth, the Labradorian. Among the Huronian is placed the Quebec group of Logan.

Huntington gives the geology of the Coos and Essex district. The Coos rocks, consisting of argillaceous schists, clay slates, and micaceous sandstones, are supposed to belong to the fossiliferous series. The Huronian rocks are found east of the line limiting the Coos group. They consist of green chloritic rocks, in which the lines of stratification are obscure. Included are greenish feldspathic sandstones, with intercalated bands of siliceous limestones. There are also here contained stratified diorites, diabases, and hornblende rocks. The porphyry which occurs connected with the Coos and Huronian penetrates the rocks with which it comes in contact, and the intrusive character can not be doubted. Outcrops of granites and granitoid gneisses have a wide extent, a part of them being regarded as genuine eruptive granites, since they intersect the schists in numerous veins and beds. The basic dikes are the latest of all, cutting the granites and intersecting the schists at many places.

Hitchcock gives the formations of the White Mountain district as follows, in ascending order: (1) Porphyritic gneiss; (2) Bethlehem gneiss; (3) Berlin or Lake gneiss; (4) Montalban group; (5) Franconia breccia; (6) Labrador system or Pemigewasset series of granites, ossipytes, compact feldspars, etc.; (7) syenite; (8) andalusite slates; (9) Pequawket or Mount Mote granite. The three first are regarded as metamorphic, although the stratification is destroyed. The Montalban group includes granitic gneiss, mica schist, and quartzite. The granitic gneiss sometimes shows no visible mark of stratification, as in the Concord granite, although the whole is regarded as metamorphic. An unconformity is inferred between the Montalban schists and the porphyritic gneiss on account of the divergence in the strike of the two groups. Eruptive granite is found in the Montalban schists. The Franconia breccia is placed later in the chronological scale than the Montalban group, because it is the impression of the author that he has seen Montalban fragments in this rock. The Labrador system is considered as the probable equivalent of the Labrador system of Logan and Hunt. It includes the Conway granite, Albany granite, Chocorua granite, ossipyte or labradorite rocks, and various compact and crystalline feldspars or porphyries. The relations of the Albany granite and the andalusite slate do not show that the underlying granites are certainly not sediments, although they have been so thoroughly metamorphosed as to have lost their lines of original bedding; but the evidence in favor of their eruption since the deposition of the andalusite slates is increasing. The slates are twisted and broken in many places, the fragments being cemented together by a granitic paste; also, fragments of slate occur embedded in the underlying granite. The Labrador group is found in seven areas. The Labrador rocks lie unconformably upon the upturned edges of the Montalban gneisses, the discordance varying from 45° to 70°. Porphyry occurs in this system, which is regarded as intrusive. Syenite has a rather widespread occurrence. The andalusite slates are regarded as the equivalent of the Coos series, but they are similar to the Huronian system. The Pequawket series is regarded as late eruptives. The stratigraphic order in the White Mountains is finally concluded to be as follows: (1) The Laurentian, represented by the porphyritic gneiss and the Bethlehem group; (2) the Atlantic, consisting of the Lake or Berlin and Montalban gneisses and the Franconia breccia; (3) the labradorite; (4) the Huronian; (5) the Merrimac schists; (6) the andalusite schist group; (7) eruptions of porphyry; (8) eruptions of the Conway, Albany, and Chocorua granites and syenites; (9) the formation of the Mount Pequawket or Mount Mote porphyritic breccia. This order is somewhat different from that stated at the beginning of the chapter. The Huronian barely touches the White Mountain area. With it are placed certain quartzites which are lithologically like those of Canada. The Green Mountain and White Mountain gneisses are regarded as Eozoic because they are a continuation of the Eozoic rocks of New Jersey and New York, because they are bordered by quartzites of Cambrian age which dip away from them both to the east and to the west, because the Labrador series is present, and because fossiliferous Helderberg strata are found on both the east and the west sides of the White Mountains side by side with the metamorphic schists, the former containing fossils.

In the Ammonoosuc gold field of the Connecticut Valley the following succession is found: (1) Laurentian, consisting of the porphyritic and Bethlehem gneisses; (2) Atlantic gneiss, represented by the Lake division; (3) Huronian, embracing the Lisbon and Lyman groups and the auriferous conglomerate; (4) Cambrian clay slate; (5) Coos group; (6) Swift water series; (7) Helderberg quartzites, slates, and limestones. The Huronian formations embrace schists, conglomerates (the pebbles being sometimes flattened), quartzites, dolomites, and jaspers.

In the area between Haverhill and Claremont the subdivisions are as follows: (1) Bethlehem gneiss; (2) Huronian, with three or four subdivisions; (3) Cambrian clay slate; (4) Coos quartzites; (5) Coos slates and schists; (6) calciferous mica schist; (7) eruptive granites, including the Mount Ascutney area, which is partly composed of rocks older than Huronian.

In the Connecticut Valley district, between Claremont and Hinsdale, the succession is as follows, beginning with the lowest: (1) Bethlehem gneiss; (2) gneisses of the Montalban series; (3) Huronian; (4) Coos quartzites; (5) Coos slates and schists; (6) calciferous mica schist; (7) eruptive granite. The Coos quartzites and calciferous mica schists are only semicrystalline rocks, all the thoroughly crystalline schists being placed with the pre-Cambrian. The thickness of the Huronian rocks in New Hampshire is placed in the neighborhood of 10,000 feet.

Huntington gives the order of superposition of the rocks in the western part of the Merrimac district as follows: (1) Porphyritic gneiss; (2) Bethlehem or protogene gneiss; (3) common or Lake gneiss; (4) ferruginous concretionary schist; (5) fibrolite schist, sometimes gneissic and passing into common mica schist; (6) quartzites and quartz conglomerates; (7) intrusive rocks and veinstones. Hitchcock gives the order in the eastern part of the district thus: (1) Porphyritic gneiss; (2) Lake gneiss; (3) Montalban series, including the Concord granite; (4) ferruginous schist; (5) andalusite mica schists, with coarse granite veins; (6) Rockingham mica schists; (7) Kearsarge andalusite group; (8) Merrimac group, including a little clay slate. There are no eruptive rocks in this area of sufficient importance to find a place on the map.

Hitchcock gives the succession in the Lake district, embracing the Winnipiseogee Lake and the flat country to the north, as follows: (1) Porphyritic gneiss; (2) Lake gneiss; (3) Montalban. The eruptive rocks are more plentiful and varied, consisting of (1) Conway; (2) Albany; (3) Chocorua granites; (4) porphyry; (5) Pequawket breccia; (6) labradorite diorite; (7) syenite; (8) granite, not allied to any of the foregoing.

The succession in the coast district, including the southeast corner of the State, is as follows: (1) Porphyritic gneiss; (2) Lake gneiss (including the Laurentian of Massachusetts); (3) Montalban; (4) Rockingham group; (5) Merrimac group; (6) Kearsarge group; (7) Huronian and Cambrian of Massachusetts. The unstratified rocks are the syenites of Exeter and Pawruckaway, inferior granites, and the well-developed granites and porphyries of York County, besides a great many trap dikes along the coast.

In considering the principles of classification, as guiding principles it is premised that in this field are inverted flexures and dislocations of the strata; also that formations of the same mineral composition in one part of the field may be identified with those of like composition in another part of the field. For instance, the porphyritic gneiss in thirty areas has feldspar crystals very conspicuous for their size; all these areas are assumed to be identical in age, and in placing the relative positions of the intervening groups this is relied upon for a starting point. The general order of succession for New Hampshire is, from the base upward: Porphyritic gneiss; Bethlehem gneiss; Lake and Montalban series; argillaceous, talcose, hydromicaceous, and calcareous series; Labrador series (present in New Hampshire, limited in amount); various types of mica schists. Andalusite slate in this mica schist formation lies unconformably upon the Montalban at Mounts Monadnock and Kearsarge. The principal eruptive masses are the Conway, Albany, Chocorua granites, syenites, other granites, and labradorite, diorites, and dolerites. The granites cut rocks as high as the Coos group. The porphyritic gneiss and the Bethlehem group are referred to the Laurentian. The Lake gneiss can not easily be assigned. The Montalban certainly is not characteristic of the Laurentian, but all of the preceding are regarded as underlying the Huronian. It is thus concluded to place the porphyritic, Bethlehem, and Lake gneisses with the Laurentian, leaving the position of the Huronian and Montalban to be settled by other considerations.

The Huronian is divided into two divisions—the upper chloritic and the lower quartzose feldspathic. The greenstones seem to be closely allied to the Upper Huronian and the porphyries to the lower division, and to this may belong the supposed eruptive porphyries of the White Mountains. The Merrimac, Rockingham, and Kearsarge mica schists are somewhat related to the Huronian, as well as to the Cambrian. They are all referred doubtfully to the Paleozoic system. The thickness of the doubtful Paleozoic is placed at 11,600 feet; the Upper Huronian, 12,129 feet; Lower Huronian, not estimated; Montalban, 13,700; Laurentian, 34,900. The Labrador system if present in New Hampshire is in very limited amount. Certain of the labradorites are surely injected dikes, and hence it is doubtful whether the Waterville area really represents the Labrador system of Canada.

HAWES,[13] in 1878, regards the diabases, diorites, gabbros, felsites, granites, and syenites of New Hampshire as eruptive rocks. Some of them may have been produced by the fusion of sediments, but, however this may be, they have all been in a molten condition and been free to crystallize. There are beds of granite which are unconformable with the associated stratified rocks, granites filling well-defined dikes, granites which so far as can be seen are entirely devoid of structural relations, and granites which are mixed with other rocks or which hold huge fragments of other rocks inclosed in their masses. All these features are often repeated. Among the crystalline schists are placed gneiss, mica schist, argillitic mica schist, and quartz schist. The gneisses, like the granites, are believed to be of eruptive origin, or at least to have acted like an eruptive rock, the lamination being an induced structure which may or may not correspond with original bedding in case they are completely metamorphosed material. The gneisses in their minerals, inclusions, and microscopic characters are like granites, and pressure may have been as effective in producing lateral movements and forming foliation in a plastic mass as sedimentation. If, then, the stratification of the gneiss is regarded as an induced structure, it would not follow that the stratification should correspond with the original bedding; and even if the lamination does correspond with the plane of the strata, the lamination can not be referred to stratification of sediments, for the cleavage of the adjacent rocks may also be due to pressure and be different from the plane of bedding. The greenstones, including metamorphic diorite, quartz diorite, and amphibolite, are regarded as metamorphosed sedimentary rocks. These have marked lithological distinctions from the fresh basic rocks recognized as eruptives. The clay slates and quartz schists are semicrystalline rocks. The slaty cleavage and bedding are sometimes discordant.

Hawes,[14] in 1881, describes the Albany granite as penetrating and metamorphosing the schists, and as having a porphyritic structure near its contact with them, and it is therefore concluded to be intrusive.

Hitchcock (C. H.),[15] in 1890, regards the oval granitoid areas occurring in the White Mountains, about which occur foliated rocks with an anticlinal quaquaversal arrangement, as the oldest known or fundamental rocks of the region, which are remains of an ancient archipelago.

Williams,[15] in 1890, with the same facts before him, gives an interpretation exactly opposite to that of Hitchcock—that is, that the central granites are younger intrusive masses.

Hitchcock (C. H.),[16] in 1896, gives a general account of the geology of New Hampshire, including a sketch of the work and conclusions of the first and second New Hampshire State surveys and of subsequent workers in the field. Some of the modifications indicated by work done since the close of the second State survey are: (1) Archean rocks exist as oval areas in the Stamford gneiss and south of Mount Killington, Vt., in the Hinsdale, Mass., area, the Hoosac Mountain, and elsewhere. (2) The masses of Bethlehem gneiss are batholiths, with inclusions of adjacent mica schists. (3) A study of several areas of hornblende schist proves that they are igneous.

Daly,[17] in 1897, discusses the porphyritic gneiss of New Hampshire, and concludes that it is an eruptive porphyritic granite, at least in its three most important areas, of post-Devonian age.

Hitchcock,[18] in 1904, concludes that a long list of what were formerly called metamorphic schists may now be classed as eruptive igneous rocks, such as the porphyritic granite, Bethlehem granite, Lake gneiss, diorites, and protogenes, to say nothing of what has always been recognized as granite and diabase. The periods of their extrusion were evidently middle or late Paleozoic. The general results of his studies tend to restrict the areas of the more ancient rocks, and to increase those representing the Paleozoic groups in the adjoining regions of northern New England.

SECTION 3. VERMONT.

SUMMARY OF LITERATURE.

Adams,[19] in 1845, divides the older rocks of Vermont into Primary strata and Paleozoic rocks. The Primary system is highly crystalline and destitute of fossils. It is divided into argillaceous slate, calcareo-mica slate, mica slate, talcose slate, Green Mountain gneiss, and gneiss proper, which however does not represent the order of superposition, as the strata are involved in great confusion. The marbles of the State are divided into three systems—Primary, Taconic, and New York. There are few Primary marbles in the State. The Taconic marbles occur throughout the range of limestone from Massachusetts to the northern part of Madison County. The Taconic system includes roofing slate, Taconic slate, Sparry limestone, magnesian slates, Stockbridge limestone, and granular quartz rock.

ADAMS,[20] in 1846, includes the Taconic and Primary systems of his previous reports under the general term Azoic stratified rocks, as simply expressing the fact of the absence of organic remains, for it is not to be assumed that the Azoic Taconic rocks are more ancient than the Paleozoic, and the same remarks may be said of the so-called Primary rocks, not a small portion of which may be as metamorphic and recent as the Champlain rocks. In the Green Mountains are quartz rock, gneiss, talciferous limestone, quartz gneiss, and limestone, which are supposed to be Taconic. Dikes of greenstone cut through all the divisions of the stratified rocks and are therefore more recent than any of them.

ADAMS,[21] in 1847, gives additional details as to the rock occurrences in particular localities.

THOMPSON,[22] in 1856, states that the Green Mountains form the center of an anticlinal axis, the dips increasing both east and west from the principal summits. Slates, schists, and quartzites are found, which contain a few obscure fossils and are referred to the Taconic system.

HITCHCOCK (EDWARD),[23] in 1861, divides the rocks in general into stratified or aqueous and unstratified or igneous. With the latter are placed granitic, trappean, and volcanic rocks. The former are subdivided into fossiliferous and unfossiliferous, or Azoic. In this latter division are placed clay slate, quartz rock, mica schist, talcose schist, and chlorite schist, steatite or soapstone, serpentine, hornblende schist, gneiss, and crystalline limestone. The important practical question with respect to the metamorphic rocks is, What was the original rock from which the metamorphosed deposit was derived? In not a few instances so complete has been the metamorphism that it can not be told whether the rock belongs to the oldest of the crystalline rocks or is earlier than the Silurian or Cambrian. While the degree of metamorphism gives no clue as to the age of the rocks, from other evidence it is probable that most of the highly metamorphosed rocks of Vermont are altered Devonian and Silurian. In the western part of the State, and especially that part of New York that lies southwesterly, are found these fossiliferous rocks but little altered, and these form a starting point for the Green Mountain rocks and those farther east.

Metamorphism is made to apply to any transformation of any kind of rock into another. At Newport, R. I., and East Wallingford and Plymouth, Vt., are found schist conglomerates in which the pebbles are elongated very much in the direction of their strike. They are flattened, but not so strikingly as elongated, are indented deeply into one another, are sometimes a good deal bent, and are cut across by parallel joints and fissures. At times the process has gone so far as to merge the pebbles together, so that they scarcely present the appearance of ordinary pebbles. If the talcose conglomerate schist is looked at on the edge corresponding to the dip, nothing is seen but alternate folia of quartz and talc and mica, and the rock would be pronounced a good example of a talcose schist. But a fracture at right angles reveals the flattened pebbles and shows that what have been regarded as folia are their edges. If the process of flattening had been carried a little further no evidence would remain that they were ever pebbles. How extensively the process has been operative, thus producing schists and gneisses from conglomerates in the Green Mountains, is unknown. No examples of undoubted pebbles in a gneiss have been found.

At Whately, Mass., on Ascutney, and at Barnet and Granby, Vt., are conglomerates which have as a matrix granite and porphyry. The granite sometimes passes into syenite. At Ascutney the syenite abounds in black, rounded masses which are for the most part crystalline hornblende and feldspar, and are probably transmuted pebbles. At Granby the pebbles, manifestly rounded, are either mica schist or white, almost hyaline, quartz, just such as form the pebbles in the conglomerates at Wallingford and Plymouth, and the base is a fine-grained syenite, passing sometimes almost into mica schist. A pebble of hornblende schist is also sometimes seen. In bowlders of this conglomerate found at Northampton, Mass., and probably derived from Whately, the most abundant pebbles are those of the brown sandstone, considerably metamorphosed and flattened. Those of hornblende schist are common. Sometimes they are merely crystalline hornblende, not foliated generally, however, but mixed with some feldspar; and they may become syenite, and are frequently porphyritic by distinct crystals of feldspar. The cement is syenite, often more hornblendic than usual. When the pebbles are highly crystallized they become so incorporated with the matrix that it is difficult to separate them with a smooth surface, and apparently they pass insensibly into those rounded nodules, chiefly hornblendic, so common in syenite, especially that of Ascutney. These occurrences are regarded as proof that the completely crystalline granular matrix is a metamorphic rock.

The pre-Potsdam rocks of Vermont are called Laurentian or Hypozoic, although it does not follow that they are not equivalent with the fossiliferous series elsewhere. It is only believed that if fossils once existed in them they have been obliterated. Of the Hypozoic rocks, Vermont contains, so far as known, only a small belt, which is the eastern edge of an immense development of the same in New York. These are referred here because there seems to be a discordance in the stratification between these rocks and the Lower Silurian, to which they are adjacent. The oldest of the Paleozoic series lies directly upon the Hypozoic, at least at one point. As we approach the Green Mountains, metamorphism has so nearly destroyed the fossils that the identification of the strata becomes extremely problematical, until at length the clue is lost entirely and the age of the formations can only be conjectured; hence they are distinguished mainly by lithological criteria and are grouped into a third class, Azoic rocks. Probably most of the Azoic rocks of Vermont will be found to be more recent than the Laurentian of Logan. The fossiliferous rocks are sometimes found under those that are more crystalline and nonfossiliferous, and these cases are thought to be the result of inversions. Certain great thicknesses of schists of uniform character are regarded as folded several times so as to be vertical, because otherwise the thickness of the series would be enormous. The talcose conglomerates, talcoid schists, Georgia group, etc., are referred to the Potsdam and later formations. The Georgia group and sand rock may possibly be Primordial. The talcose conglomerate is placed as a continuation of the Quebec group and Sillery sandstones of Canada. The Taconic system is regarded as having an extension into Vermont, and to it are referred the black Taconian roofing slates, Sparry limestone, magnesian slate, Stockbridge limestone, and granular quartz rock, with associated talcose beds, the thickness of the whole being 25,200 feet.

It is supposed that the chief action of metamorphism was in the Laurentian system and that the cases of subsequent thorough alteration were exceptional. The theory of the Laurentian age of the Azoic rocks of New England and the theory of the Cambrian age of the Taconic system stand or fall together. The Taconic system is regarded as older than the Lower Silurian and newer than the Laurentian, because it underlies the Silurian, because it is immensely thicker, and because the fossils which it contains are different from those of the Silurian.

Hitchcock (C. H.),[24] in 1861, gives a lithological treatment of the Azoic rocks of Vermont. They are divided into the following groups, which are described in detail: Gneiss, hornblende schist, mica schist, clay slate, quartz rock, talcose schist, serpentine and steatite, and saccharoid limestone. Cleavage has a widespread occurrence, although it is believed that the strike and dip of lamination and stratification generally correspond. The granite gneiss approaches so near to granite that in hand specimens the two rocks can not be distinguished from each other. The granite of the two Ascutneys seems to have cut across the strata of the calciferous mica schist and a considerable distance into the gneiss, although the granite is regarded as of metamorphic origin. Clay slate often passes by insensible gradations into mica schist, which is regarded as a modified fragmental rock. Associated with the talcose schists and constituting an integral part of the formation are clay slate, gneiss, quartz rock, sandstones, and conglomerates. Igneous rocks, both trap and granite, are also associated with this formation.

Hitchcock (Edward),[25] in 1861, considers in detail the relations of the granitic to the other rocks and also the origin of the granite. This rock is found interstratified with slate, limestones, and mica schists in many localities. At the "Narrows," in the northern part of Coventry, the number of alternations is very large, the thickness of the different layers of granite varying from 1 to 7 feet.

The conglomeratic syenites of Whately, Mass., and Ascutney, Granby, and Barnet, Vt., which contain fragments, are described in detail. These may be described as conglomerates whose cement is syenite, or as a syenite through which are scattered pebbles mechanically rounded. Generally the pebbles have been more or less metamorphosed, and sometimes almost converted into syenite, subsequent to their introduction. In their present state white quartz, mica schist, hornblende schist, and hornblende have been noticed. At Ascutney all traces of stratification in the conglomerate are lost and it passes first into an imperfect porphyry and then into a granite without hornblende in the same continuous mass. Where the conglomerate is least altered it is made up almost entirely of quartz pebbles and a larger amount of laminated grits and shales, the fragments rounded somewhat, and the cement in small quantity. The fragments are sometimes metamorphosed to mica schist. The conviction can not be resisted that the granitic rocks of this mountain are nothing more than conglomerate melted down and crystallized. At Granby the bowlders are of all sizes, from a few hundred pounds to 50 to 60 tons. They cover many acres, and are associated with those of contorted mica slate, quartzose granite, and many other varieties common in the region.

At several localities in Vermont—Craftsbury, Northfield, New Fane, Proctorsville—and at Stanstead, just beyond the Canada line, is a remarkable variety of white, fine-grained, highly feldspathic granite which contains scattered through its face numerous spherical or elongated and somewhat flattened nodules of black mica from half an inch to 2 inches in diameter. They are usually more or less flattened and have a shriveled appearance, like dried fruit. In some cases the concretions occupy more than half the mass. These concretions have sometimes been called petrified butternuts. The rock is regarded as produced by the metamorphism of a stratified rock.

Veins of granite are found to cut syenite, schist, gneiss, and limestone, in a most intricate manner at many localities. Sometimes there are several generations of granite veins. The foregoing facts lead to the conviction that the granite acts essentially like a liquid mass, but it is regarded as the product of aqueo-igneous fusion rather than dry fusion. Also it is believed that for the most part the granites have formed in situ, their material being furnished by the sedimentary rocks; hence they are called metamorphic. As evidence that they are metamorphic is cited the fact that it is often difficult to tell where a gneiss ceases and a granite begins. It is sometimes found, where granite masses come in contact with stratified rocks, that the latter have been more or less disturbed and broken, but only to a limited extent, and often not at all. In many cases also the adjoining strata have suffered mechanical displacement, such as the forcible injection of melted matter would produce. For a considerable distance around the granitic masses, also, the strata are frequently indurated and metamorphosed as if by heat, a fact that seems to decide the question of the emanation of much heat from granitic foci. The granites are more abundant in the crystalline than in the fossiliferous series; in fact, it is uncertain whether any occur in rocks which bear fossils, although they are found in those which are regarded as the equivalent of the Devonian. The granite is most common in gneiss and mica schist, less so, especially in the form of veins, in clay slates, and least of all in talcose schist. In the stratified rocks cleavage and foliation occur, while joints are found in both the stratified and the unstratified rocks.

Thompson,[26] in 1861, describes the greenstone or trap dikes of parts of Vermont. These are found to cut all the other rocks at many localities. Besides these there occur calcareous dikes, veins and dikes of quartz, and metallic veins.

Hitchcock (C. H.),[27] in 1861, gives detailed descriptions of sections in Vermont. The relations of the Ascutney syenite to the stratified rocks are again described. In the ledges immediately contiguous to the granite most powerful marks of alteration by heat are found. The syenite is surrounded, to a distance of a quarter to a half mile, with indurated schists that ring like pot metal when touched with a hammer, and the lime rock that is usually arranged in separate strata seems to have become a constituent part of each stratum, the whole rock resembling the compact vitrified quartz west of the Green Mountains. Often crystals of staurotide, and perhaps scapolite, are formed in the schist by the heat. In the west part of the larger mountain there are enormous veins crawling round in all conceivable directions in former crevices among the schists. This syenite is full of nodules of hornblendic masses, which look in some cases much like pebbles. They are probably concretionary, and are all allied to the concretions of black mica in granite at Craftsbury and elsewhere.

Hall (S. R.),[28] in 1861, gives many details as to the geology of northern Vermont. The granites are here particularly abundant. The occurrences are such as to lead to the conclusion that they are eruptive and that in their eruptions fragments have been caught from the strata cut. As evidence that the granite has been thrown up since the mica schists were formed is cited the fact that the slates on the borders of the granite furnish unmistakable signs of contortion and in some instances of change both in the direction of the strata and in their dip. In more than one instance granite is found overlying the calcareous mica slates, and in one instance, at Derby, encrinite limestone occurs below granite. In many places jointed granite is found between the strata of slates, conformable to them, and in other instances in dike form, crossing the strata at a large angle. Fragments of the older slates are, in many places, found embedded in masses of granite and retain the characteristics of the slates, without any essential change. Nodular granite, containing masses embedded like plums in a pudding, run from Memphremagog Lake through Derby, Brownington, Irasburg, Craftsbury, and Calais.

Hitchcock (C. H.),[29] in 1868, gives the following succession for the rocks of Vermont: Unstratified rocks, including granites, syenite, protogene, with the traps and porphyries; Eozoic system, including Laurentian gneiss of West Haven and the Green Mountain gneiss; Paleozoic system, in which are placed the Georgia slates, the talcose conglomerate and schists, the mica schists, and other formations.

Hunt,[30] in 1868, states that there is no evidence of the existence in Vermont of any strata, except a small spur of Laurentian, lower than the Potsdam formation. The so-called middle and lower Taconic is in part Potsdam and in part Utica, Hudson River, and Quebec.

McCormick,[31] in 1887, describes the inclusions in the granite of Craftsbury. The inclusions are spheroidal or elongated nodules of biotite 1½ to 2 inches in diameter, and sometimes 4 inches long, cemented with quartz, which by Hitchcock were compared to butternuts. The line of contact between the inclusion and the rock is usually rather distinct, it being possible to extract the former, leaving a lining of biotite. It is concluded that these nodules indicate the igneous origin of the granite, because they could not have been formed from aqueous solution or by metamorphic action.

Whittle,[32] in 1894, describes the main axis of the Green Mountains as a series of sharp, compressed folds striking approximately north-south and overturned to the west in most localities, so that induced schistosity and stratification dip eastward, but the exact angle at which the strata lie is difficult of determination. Localities on the western border have a steep westerly dip in many instances; in others the border series as a whole is in a nearly vertical position. The orographic thrust producing the folding was directed nearly east and west. Normal faults and overthrusts are indicated, but data for their detection are not now at hand except in one instance.

WHITTLE,[33] in 1894, describes the pre-Cambrian rocks of Vermont as consisting of two series of Algonkian rocks. The Lower Cambrian quartzite is apparently underlain conformably by the upper of the two, or the Mendon series. That the two are, however, really unconformable is supported by the following reasons among others: The extreme lithological diversity of the metamorphic series as compared with the quartzite; a close folding in the Mendon series not observed in the quartzite, and the fact that toward the south the quartzite reposes discordantly upon granitoid gneiss.

The Mendon series consists in descending order of the following members: Mica schists, with a maximum thickness of 1,000 feet; micaceous quartzite, having a maximum thickness of 500 feet and carrying several thin beds of crystalline limestone; crystalline limestone, with a maximum thickness of 400 feet; conglomerate schists and quartzite, with a maximum thickness of 700 feet. At Mendon the section has an approximate thickness of 1,300 feet, and in some localities there may be 2,000 feet of strata in the series.

The lower series of Algonkian, called the Mount Holly series, is contrasted with the Mendon series in nearly every way. The structure of the series is so complicated, the different rock types vary so greatly, and the series has been subjected to such a multiplicity of dynamic movements, that no definite stratigraphy has been made out. Some of the prominent rocks of the series are biotite schist, muscovite schist, garnetiferous schist, vitreous quartzite, augen gneiss, and various kinds of limestone. The limestones are in irregular lenses and are extremely local. There may be two horizons of limestone or a dozen. The series, because of the undoubted areas of sedimentary rocks which have escaped destruction, are regarded as clastic. Associated with the above rocks are very abundant schistose igneous rocks, comprising both dikes and sheets.

The two series of Algonkian rocks are regarded as unconformable for the following reasons: Between the two there is a great lithological difference; the Mount Holly series has been cut through by eruptive rocks in a complicated fashion, and these do not occur in the Mendon series; the Mount Holly series is folded in a much more intricate manner than the Mendon series, and secondary structures have developed to a far greater degree; at the bottom of the Mount Holly series is a widespread formation of conglomerates and gneiss.

The schistosity of the two series is parallel, but this is regarded as due to disintegration before the Mendon series was deposited and to post-Mendon folding.

RICHARDSON,[34] in 1902, notes the distribution of "Huronian" rocks in Orange County, Vt. These consist of magnetitic and garnetiferous chlorite and mica schists, with beds of serpentine and soapstone as alteration products. They are also associated with granite, diorite, and gneiss.

RICHARDSON,[35] in 1906, discusses the areal and economic geology of northeastern Vermont. Flanking the Green Mountains on the east are pre-Cambrian chlorite schists, micaceous quartzites, and gneisses, carrying serpentine and asbestos deposits. No attempt has been made to determine the structural features except near its contact with the Waits River limestone on the east.

An eastern belt lies directly west of Connecticut River. It stretches across Essex, Caledonia, Orange, and Windsor counties, reaching a breadth of 5 to 10 miles in Essex County and becoming a narrow band south of Wells River. Lunenburg schist is the chief pre-Cambrian representative in the eastern belt. Through this Connecticut River has cut its sinuous channel along the interstate boundary. It is a highly metamorphic, green, greasy, chlorite schist, in many places studded with pyrite. The eastern border of the Lunenburg schist is cut by several outcrops of protogene gneiss.

Flanking the Lunenburg schist in the west is a narrow belt of sheared quartzite. Although no fossils have been found in the Lunenburg schist and in this quartzite in the areas of the least metamorphism, it is believed that their true stratigraphic position is Cambrian. A rather wide belt of metamorphic feldspathic schists occurs in Concord and Waterford. It is suggested that the Lunenburg schist itself will be found to be Paleozoic.

SECTION 4. MASSACHUSETTS.

SUMMARY OF LITERATURE.

HITCHCOCK (EDWARD),[36] in 1818, divides the Primitive rocks of a section of Massachusetts on Connecticut River into syenite, granite, and argillite, alternating with mica slate, siliceous slate, and chlorite slate.

DEWEY,[37] in 1818, states that the country of the Taconic Range and Saddle Mountain is principally Primitive. Granite is found on both sides of Hoosac and Pownal mountains. Gneiss and mica slate are found on Hoosac and Saddle mountains. The Taconic Range is composed principally of a talcose or soapstone slate, but quartz, granular limestone, and argillaceous slate are found. Quartz occurs on Stone Hill, above which is argillaceous slate. Granular limestone occurs on both sides of the Hoosac. Argillaceous slate occurs in the valleys connected with the limestone.

Dewey,[38] in 1820, finds the section from the Taconic Range at Williamstown to the city of Troy to consist of chlorite slate, graywacke, and argillaceous slate, this being the order of succession. The strata all incline to the east from 10° to 40°, the general inclination being 20° or 25°.

Hitchcock (Edward),[39] in 1823, describes granite as occurring at many localities in the region contiguous to Connecticut River. It sometimes shows a tendency to stratification—at Southampton it occurs in beds in the mica slates and at Bellows Falls it grades into mica slate—and frequently veins of it cut the strata. These veins divide and subdivide, like the top of a tree. In this region are also found gneisses, hornblende slate, mica slate, talcose slate, chlorite slate, syenite, greenstone, argillite, and limestone, all of which are referred to the Primitive. The gneiss is the most abundant rock, and often alternates with mica slate and passes into it. The dips of the layers are from 20° E. to 90°. At Hatfield, by following up the syenitic ridge, a rock is found which contains numerous embedded masses of other Primitive rocks; these embedded fragments are almost uniformly rounded, and in many places are so numerous as to make the rock appear like a real Secondary conglomerate. Thus we have a really conglomeratic syenite. The Primitive greenstones are distinguished from the Secondary because the latter are more coarse and crystalline.

Dewey,[40] in 1824, in a sketch of the geology of western Massachusetts, divides the principal rocks into granite, gneiss, mica slate, granular limestone, argillaceous slate, quartz rock, Transition limestone, and graywacke, mica slate being the most abundant rock. The granite is not stratified, and must be considered as beds or veins rather than a continuous rock like the mica slate. In the town of Windsor is a conglomeratic mica slate.

Nash,[41] in 1827, finds the rocks of Hampshire County to include granite, mica slate, micaceous limestone, hornblende rock, talcose slate, Old Red sandstone, etc. The limestone often alternates with mica slate, and frequently passes into it by insensible gradations. It is in many places garnetiferous. The granite veins are of all sizes up to 3 or 4 feet, cut the rocks in every possible direction, and intrude granite as well as the mica slate.

Hitchcock (Edward),[42] in 1833, divides the rocks of Massachusetts into stratified and unstratified. Below the New Red sandstone in the former are graywacke, argillaceous slate, limestone, scapolite rock, quartz rock, mica slate, talcose slate, serpentine, hornblende slate, and gneiss. The unstratified rocks are greenstone, porphyry, syenite, and trap, each of which is discussed. Among the agents which have consolidated the rocks heat is predominant, although chemical action has played an important part. The mica slates have been mechanically deposited in water, and subsequently subjected to such a degree of heat as to enable their materials to enter into a crystalline arrangement without destroying their structure. The granite is supposed to have resulted from the melting down of other rocks. Where it is completely melted, granite results; where partially fused, granite gneiss is found; while another portion might be converted into porphyritic gneiss and another into schistose rock. This theory explains the gradation of gneiss into granite and the crystalline and porphyritic structure of the gneiss. The unstratified rocks are all igneous. They occur in irregular protruding masses, in the form of veins of various sizes, and as overlying masses. In cases in which they exist interstratified with other rocks, an examination shows that such interlaminated masses are always connected with an unstratified mass, and are merely veins which for a time coincide in direction with the strata. The syenite quarries of Sandy Bay, Cape Ann, have a parallel lamination, but as these grade into an unstratified syenite they are considered as examples of concretionary structure on a large scale rather than as a result of real stratification.

Hitchcock (Edward),[43] in 1841, in a systematic account of the geology of Massachusetts, divides the rocks below the New Red sandstone into the following classes: Graywacke, metamorphic slates, argillaceous slate, limestone, quartz rock, mica slate, talcose slate, serpentine, hornblende slate, gneiss, greenstone, porphyry, syenite, and granite. From the graywacke to the gneiss this is the order of occurrence. The greenstone, porphyry, syenite, and granite are regarded as eruptive. At Bellingham is a remarkable metamorphic rock, which is a distinct mica slate and a no less distinct conglomerate. In this formation are also placed aggregates of porphyry, which is a coarse breccia or conglomerate, chiefly made up of fragments of porphyry reunited by a cement of the same material, and sometimes almost reconverted into a compact porphyry. Flinty slate, chert, and jasper are simply the ordinary slate changed to an unusual condition by the proximity of granite, porphyry, or trap. The clay slate is entirely destitute of organic remains, as is also the graywacke. The limestones are water-deposited stratified rocks metamorphosed by heat. The mica slate is generally associated with gneiss, but also occurs associated with all other rocks at least as high as the argillaceous slate. Hornblende schist and greenstone slate, a single formation, are tentatively regarded as metamorphosed from ordinary argillaceous rock by the action of heat. Gneiss is often much folded and curved, and is cut by veins of other rocks, but is regarded as in general regularly stratified.

At Whately occurs a peculiar conglomeratic syenite, which is generally found between the granite and metamorphic rocks and may be due to the conversion of the granite into syenite or else to the eruption of the syenite at a different epoch. The pseudo stratification of granite is regarded as due to concretionary action on a gigantic scale. The granite cuts and is interstratified with all the stratified rocks and certain of the other eruptives in the most intricate fashion.

In Massachusetts are six systems which are unconformable and succeed one another in age. These are as follows: The Oldest Meridional system, the Northeast and Southwest system, the East and West system, the Hoosac Mountain system, the Red Sandstone system, the Northwest and Southeast system. In western Massachusetts, from Hoosac Mountain to the Taconic Range, a powerful force has folded the strata so that in many cases they have actually been reversed.

LYELL,[44] in 1844, describes the plumbago and anthracite in the mica schist near Worcester. This is in the immediate neighborhood of masses of granite and syenite, the character of the plumbago and anthracite being due to this local metamorphosing effect and to more general chemical or plutonic action. The difference in dip of these rocks from the nearest Carboniferous of Rhode Island and Massachusetts is no evidence that they are not equivalent and that the graphite is not metamorphosed organic material.

ROGERS,[45] in 1857, describes trilobites belonging to *Paradoxides* as occurring in the metamorphic beds of eastern Massachusetts at Braintree, which shows that these ancient and highly altered sediments are the base of the Paleozoic column.

HITCHCOCK (C. H.),[46] in 1859, describes the rocks from Greenfield to Claremont, Mass., as having the following order: Micaceous slates and schists interstratified with siliceous limestone, mica slate, hornblende slate, mica slate interstratified with limestone, and, lastly, calcareo-mica slate. The dip as far as the West Shelburne Falls gneiss is to the east; at this latter point it is to the west. The whole is regarded as an anticline.

GREGORY,[47] in 1862, describes Marblehead as consisting mainly of the Primitive formation. The northern part of the peninsula is greenstone, intersected by dikes of the same rock. In the southern section syenite contends with the greenstone for supremacy, for here the two rocks are thoroughly intermingled. The deposits of greenstone, syenite, and porphyry are for the most part distinct, although occasionally the greenstone grades into the syenite.

JACKSON,[48] in 1866, gives the following section at the base of South Mountain, at Chester, Mass., from the base upward: Hornblende rock, magnetic iron ore, emery bed, granular quartzite, chlorite slate and talc slate, crystallized talc, talcose slate rock, soapstone or talcose rock, mica slate. At North Mountain, separated from South Mountain by a branch of Westville River, the section is as follows: Hornblende rock, magnetic iron ore, emery 7 feet, hornblende rock, chlorite slate, magnetic iron ore 6 feet, talcose slate, magnetic iron ore 6 feet, mica slate.

SHALER,[49] in 1871, in a consideration of the rocks in the vicinity of Boston, states that there can be no doubt that the syenites of eastern Massachusetts are the oldest rocks found in the region. The quarries at Quincy show planes of separation in the syenite which can be only referred to stratification, despite the opinion generally entertained that the rocks are of igneous origin. This is evidenced by the fact that in the deeper portions of the syenite the bedding is imperfect and gradually passes, toward the exterior of the rock, into a more laminated phase. The first rocks of unquestionably sedimentary origin lie north of Quincy and consist of bedded sandstones approaching quartzite. This series is fossiliferous. The alteration of the bedded quartzite at Hayward landing is so great that the rock has assumed something of the appearance of a gneiss. In addition to these rocks, in the vicinity of Boston, are the Roxbury conglomerate and the Cambridge slates. In the latter are found evidences of organic life in the presence of numerous indistinct impressions of fucoids. It is believed that the Cambridge slates and the Roxbury conglomerate belong to the same great series of beds. As there is a coincidence in the direction of dip, it is thought that they all may eventually be found to be a part of the same series of beds as the Braintree. In some places the slates have a perfect cleavage in the plane of stratification. Over both the slates and the conglomerates are outflows of amygdaloid.

JACKSON,[50] in 1871, states that there is an insensible passage from the syenite into the greenstone porphyry. The obscurely stratified rocks on the border of the great syenite mass at Quincy prove the igneous influence of the eruptive syenite upon the upturned strata which it had elevated by its protrusion.

DANA,[51] in 1872, maintains from the descriptions of full sections that at Great Barrington is a conformable succession of quartzites, limestones, mica schists, and gneisses. The layers of quartzite are found along the strike to change to mica schist and gneiss. This series, many of them later in age than the Stockbridge limestone, is similar to the Green Mountain series, which has been regarded on lithological evidence as pre-Silurian. The Stockbridge limestone, on fossiliferous evidence, is found to be either Silurian or younger. It appears that lithological evidence is a very uncertain test as to geological age, for crystalline rocks are found later than the Stockbridge limestone, quartzite changes into mica slate, schist, or gneiss, these into hydromica slates, and these into chloritic mica slate.

Hunt,[52] in 1872, states that the rocks seen in the vicinity of Boston consist of three classes—crystalline stratified rocks, eruptive granites, and unaltered slates, sandstones, and conglomerates. The crystalline stratified rocks include felsite porphyries, nonporphyritic and jasper-like varieties, and porphyritic syenite; while the second division includes dioritic and chloritic rocks, sometimes schistose, and frequently amygdaloidal. These rocks are penetrated by intrusive granites, generally more or less hornblendic—the syenites of Hitchcock and others. At several places the phenomena of disruption and inclosure of broken fragments of rock in the granite are well seen, the lines of contact being always sharp and well defined. The third class, consisting of the unaltered argillites of Braintree, containing the Primordial fauna, were found to rest directly upon the hard porphyritic felsite of the ancient series, the line of demarcation being very distinct. At other places reddish granulites directly underlie the black argillites, and in several places quartzites with conglomerates are observed in contact with the old dioritic and epidotic rocks. The Roxbury conglomerate contains pebbles of the felsite porphyries, diorites, and intrusive granites of the older series, besides fragments of argillaceous slate.

Burbank,[53] in 1872, states that the bands of crystalline limestone that occur in the granitic gneiss which extends in a southwesterly direction from near the mouth of Merrimac River, supposed to contain *Eozoon*, are not true stratified rocks but subsequent deposits of a veinlike character. As evidence of this are cited the following facts: The principal deposits occur along the line of an anticline, filling cavities produced by the folding and falling down of portions of the included strata of the gneiss. The deposits are all of very limited extent, the largest appearing at the surface being not more than 220 feet in length and its widest part about 60 feet. The aggregate length of all the limestone deposits occurring in a line some 25 miles in length is probably less than 1,000 feet. The principal masses are coarsely crystalline magnesian limestones, homogeneous in texture and showing no traces of stratification. The various silicates occur attached to or near the inclosing walls of the cavities.

Dodge,[54] in 1875, divides the rocks of eastern Massachusetts into two groups, the crystallines and the more clearly stratified rocks among them. In the crystallines are placed the syenite and greenstone. These rocks have a dip to the west or northwest, and they unconformably underlie strata holding *Paradoxides*. For the most part metamorphism has been so complete that the rocks have entirely lost their original character. Eruptive rocks have often an appearance of schistose structure; in metamorphic syenites and diorites, on the other hand, the original stratification is often completely lost. Throughout the crystalline area there are immense masses of hornblende rock, diabase, and diorite, usually crypto-crystalline, in which no indication of sedimentary origin can be traced. The syenites consist of quartz and feldspar, with little or no hornblende. The porphyry probably belongs with the crystalline group, and pebbles of it are abundant in the Brighton conglomerates. Perhaps some of the slates are so altered in this region as to resemble real porphyry.

In the second division are siliceous slates and breccias. The siliceous slates are often much contorted. At Arlington they pass through fine grits and coarse syenites by various stages. The crystallines occupy distinct bands, separated by more recent rocks collected in the area between them. These more recent rocks are shown to be such by their position in relation to the underlying crystallines, as well as by the fact that they are composed of detritus of the latter. In places they are fossiliferous, and at Braintree contain the *Paradoxides* fauna. These stratified rocks are in part slates and in part conglomerates, the former appearing to occupy the inferior position. The conglomerates are well developed in the vicinity of Newport and Newberry. Cutting the slates and conglomerates are rocks which have been called eruptives, but so close is the resemblance in chemical and mineral composition and in appearance to the more fusible portions of the crystallines that it seems almost unreasonable to doubt that the former were derived from many deep-lying masses of the latter.

Crosby,[55] in 1876, describes and maps the Eozoic rocks of Massachusetts. They are divided into Norian, Huronian, and Montalban on lithological and chronological grounds. The lithological characters of the divisions are as unlike as the fauna of any two successive geological formations. The Norian is found in two areas in Massachusetts—that including the city of Salem and adjacent region and that which includes the seaward end of large Nahant. The Norian rocks, composed chiefly of feldspar, hornblende, and pyroxene, are in some places stratified and in other places massive. The Huronian rocks occur over a wide area, having an extreme length of 65 miles and an extreme breadth of about 40 miles. The Huronian comprises areas marked on the geological map of Hitchcock as syenite, porphyry, and hornblende slate. The rocks here included are treated under hornblendic granite, felsite, diorite, stratified rocks, and limestones, all of which are regarded as metamorphosed sedimentary beds. The Montalban includes granite, which comprises exotic, indigenous, and endogenous forms, gneiss, mica slate, argillite, and limestone. Most of the slates in the vicinity of Boston are regarded as of Primordial age, although fossils have been found only at Braintree. The argillite of Kents Island and the metamorphic slate of Newport are also regarded as Paleozoic.

Burbank,[56] in 1876, lithologically divides the formations of the Nashua Valley into (1) argillite, (2) mica slate and quartzite, and (3) granite and granitoid gneiss. With the argillite and mica slate are small beds of conglomerate, and inclosed in the gneiss are nodular masses of crystalline magnesian limestone. In the slates at Harvard and Bolton occurs conglomerate in which the pebbles in many cases are flattened, bent, and even drawn out into layers, giving an agate-like structure to the rock. The principal conglomerate beds lie between hills of granite on the west and north and mica slate and gneiss on the south, yet not a pebble of granite or gneiss has been discovered. As to the age of the Nashua rocks no positive opinion is offered, but the author is inclined to regard them as belonging to a distinct system older than the Wachusett gneiss. The mica slate appears to be interstratified with and to overlie the gneiss, and the argillite beds appear to be for the most part conformable with the mica slate.

Dana,[57] in 1877, maintains that the garnetiferous mica slate, staurolitic slate, mica schist, gneiss, and quartzite of Bernardston are Helderberg, on the ground that in these rocks are found fossils indicating this.

Wadsworth,[58] in 1879, describes the felsites of Marblehead Neck as altered rhyolites which show characteristic fluidal structure. These felsites are not stratified, and are younger than the granite on the neck, as dikes of felsite are seen cutting it. There is no passage of the conglomerate into the felsite in this locality.

Crosby,[59] in 1880, divides the Azoic formations of eastern Massachusetts into Naugus Head, Huronian, and Montalban, these terms being used on account of a lithological and stratigraphical resemblance which they bear to the Azoic divisions of other regions. The Naugus Head is provisionally regarded as equivalent to Hunt's Norian, and the Huronian older than the Montalban. The entire Naugus Head formation seems to have been plastic, and the extravasation has been so extensive that the character of the rocks changes at nearly every rod to varieties regarded as composed of metamorphosed stratified rocks. The Naugus Head series has been extensively extravasated through the superjacent Huronian formation, but is penetrated by nothing foreign to itself, the Huronian granite being never found to cut the Naugus Head series, from which the conclusion is formed that the Naugus Head is older than the Huronian. In fact, the Huronian granite pierces every rock in the region save the Naugus Head series and the newer noncrystallines, so that it can not be doubted that it overlies this ancient terrane. The latter must be regarded as the lowest, and hence the oldest, member of the succession.

The Huronian is principally composed of granite, petrosilex, diorite, hornblendic gneiss, and limestone, this being the order of age from the base upward. The petrosilex is the most characteristic rock.

In the Huronian distinctly bedded rocks are the exception. Although many apparently structureless rocks are probably really stratified, it is undoubtedly true that a large part, perhaps the greater part, of the formation has been more or less fluid, and extravasation may be set down as a characteristic structural feature. Besides cutting various rocks, the granite at many points contains angular fragments of the mica slates at the contact. The induration of the slate and conglomerate at points where they adjoin the granite, with the frequent development of amygdaloid characters, are facts which tell strongly in favor of the igneous character of the granite. The petrosilex is frequently cut by the granite, but the reverse is never the case. There is an apparent transition between the granite and the petrosilex or porphyry. The two are regarded as conformable, both having been metamorphosed from the same set of sediments, the more crystalline character of the granite being due to its greater depth. With the diorite are included all the basic rocks which have been fluid. These blend with and grade into the stratified hornblende gneisses.

The Montalban series in the area covered is the most important of the three systems. It comprises the ascending conformable succession, granite, gneiss, mica slate, argillite, and limestone, although subordinate breaks of no great importance occur. The granite acts as an exotic to a large degree, although it is believed to belong with and come from the endogenous metamorphic granite at the base of the series. The exotic granite has sometimes cut rocks as new as the Carboniferous. Granite grades into gneiss, the gneiss into mica slate, and the mica slate into argillite, in which are found the conglomerate bands. In these conglomerates in many cases the pebbles have been flattened, bent, and even drawn out into lenticular layers, developing a schistose structure. One of the best localities is that at Bellingham.

The Shawmut group is a fragmental series resting unconformably upon the Huronian terranes. The chief constituents of the Shawmut group are breccia and amygdaloids, the relations of which are somewhat uncertain. The petrosilex breccia of the Shawmut group are oftentimes very like the petrosilex of the Huronian. This group is perhaps equivalent to the copper-bearing rocks of Lake Superior, which they resemble lithologically. The Paleozoic formations form troughs which rest unconformably upon the older series.

Shaler,[60] in 1889, describes Cape Ann as consisting mainly of granite, which is cut by very numerous dikes of diabase and quite abundant ones of quartz porphyry. Squam River is an area of diorite. The relative age of the granite and diorite has not been determined.

Pumpelly,[61] in 1889, gives a systematic general account of the Green Mountains in Massachusetts. These include three principal elements—Hoosac Mountain, the Taconic Range, and the great valley between these. The mountain rocks are composed of crystalline schists, which are found to be of Cambrian and Lower Silurian age, resting on pre-Cambrian rocks. The valley has a floor of crystalline limestone or saccharoidal marble, on which are ridges of schists, both being of Lower Silurian age. The Taconic Range is a syncline in the Lower Silurian schists, the limestone foundation appearing only at its base. At Hoosac Mountain the succession is (1) granitoid gneiss, (2) quartzite conglomerate and white gneiss, (3) Hoosac phyllite, and (4) Rowe schist. On Greylock the succession is (1) Stockbridge limestone, (2) Berkshire phyllite, (3) Bellowspipe limestone, and (4) Greylock phyllite. At Hoosac Mountain the quartzite conglomerate and white gneiss appear to grade down into the granitoid gneiss in perfect conformity. At Stamford a basic dike was discovered which cuts the granitoid gneiss, but stops abruptly at the quartzite. Indeed, the quartzite sags down at this place, its layers thickening and filling the hollow. These relations are considered definite proof of an unconformity between the granitoid gneiss and the quartzite. The general transition between the two is explained by considering the granitoid gneiss as disintegrated at the time of the transgression which formed the quartzite. The quartzite conglomerate and the white gneiss are traced into each other laterally, and are therefore but different forms of a sediment of the same age, unequally metamorphosed. Across the valley the Hoosac phyllite was traced by gradual transition into the limestone; and the Stockbridge limestone, Berkshire phyllite, Bellowspipe limestone, and Greylock phyllite are all correlated with the Hoosac phyllite. In the quartzite is found the *Olenellus* fauna, hence the only pre-Cambrian rock is the granitoid gneiss. In structure Greylock is a complex syncline, while Hoosac Mountain is an anticline overturned toward the west. At the ends of the Hoosac Ridge the anticline bends nearly to an east-west direction. This is explained by regarding the granite gneiss as a rigid mass which resisted the lateral thrust, and the abnormal overfoldings as the result of compensatory movements.

WOLFF,[62] in 1889, gives a systematic account of the geology of Hoosac Mountain. The basement rock is a coarse granitoid banded gneiss, which forms the base of Hoosac Mountain proper. Crushing and development of new minerals make it perhaps impossible to say certainly what is the origin of this rock. It could perfectly well be an eruptive granite modified by metamorphism, while on the other hand its field relations show its close association with and frequent transition into coarse gneisses which seem to form a part of the detrital series.

Overlying the granitoid gneiss is a series of rocks called the Vermont formation. At one place, where perhaps folded, it is 600 or 700 feet thick. This formation contains numerous gradations from coarse gneisses similar to the basement gneiss, through finer grained banded gneisses, gneisses with but a small amount of mica, metamorphic gneiss conglomerate, and ordinary quartzite conglomerate, to quartzites. These phases pass into one another along the strike. In the metamorphic conglomerate it is difficult or impossible to separate the old quartz and feldspar from that formed in situ. The rock is considered metamorphic because of the shape of the pebbles and their distribution in alternations of coarse and fine materials, because of the diverse nature of the pebbles, including blue quartz, white quartz, granulite rock, and granite, and because of frequent transitions into quartzite and quartzite conglomerate.

At the Hoosac Tunnel the main facts brought out are that there is a large central mass of coarse granitoid gneiss (Stamford gneiss) forming the core of Hoosac Mountain; that this is flanked on both sides by the white gneiss conglomerate (Vermont conglomerate), the eastern band having a steady dip east and being overlain by the albite schist series, the western band broader, with varying dips, passing by gradual transitions into the coarse gneiss, and bounded on the west by a narrow band of the albite schist (Hoosac schist), the contact being conformable and transitional. This schist is succeeded on the west by another band of fine-grained white gneiss (Vermont), and this in turn by the limestone (Stockbridge), no contacts being observed. The structure is anticlinal.

This succession and these relations are found to correspond with the distribution in the central district of Hoosac Mountain. It is also found that the anticline of Hoosac, consisting of the Stamford gneiss, Vermont formation, and Hoosac schist, has a pitch to the north of 10° to 15°, while the western side has been overturned, which makes the beds in inverted order on the west side.

At Clarksburg Mountain the granitoid gneiss (Stamford gneiss) is overlain by Clarksburg quartzite (Vermont formation), in which Walcott has found remains of trilobites, showing it to be Lower Cambrian.

Emerson,[63] in 1890, describes the Bernardston series of rocks. The succession is here found to comprise fourteen members. The upper seven consist of alternations of mica schist and hornblende schist, after which follow quartzite, hornblende schist and magnetite, limestone, hornblende schist, quartzite conglomerate, argillite, and calciferous mica schist. The whole series is very crystalline, some parts so thoroughly so as to have been compared by Hitchcock with the Bethlehem gneiss, his basement Laurentian. In the limestones fossils are found such a character as to prove that the whole series is Upper Devonian.

EMERSON,[64] in 1890, describes the rocks of central Massachusetts, between the Berkshire limestone and the Boston basin, as consisting of a series of mica schists, quartz schists, and hornblende schists, presumably Paleozoic, and eight bands of granite and granitoid gneiss, in small part Archean, in larger part Cambrian, and in largest part intrusive. In the western part is a small row of Archean ovals, about which are the Cambrian conglomerates and conglomerate gneisses, the latter rocks having a quaquaversal arrangement. Here are included the Princeton and Athol granites, often well foliated, which have a great extent north and south. To the great intrusive masses of granite is applied Suess's name batholiths. These have melted their way through a great thickness of folded strata and absorbed much of the latter in their own mass. At times the central masses of granite are cut by dikes of coarse muscovite granite, which seem to be later intrusions. About the batholiths are broad areas in which contact metamorphism has altered the rocks, changing the argillites to mica schists, etc. The contact metamorphism has a zonal character. The Barre and Orange bands of biotite granite so combine the peculiarities of the Cambrian conglomerate gneisses and the batholithic gneisses that no opinion is expressed as to their origin.

PUMPELLY,[65] in 1891, describes Cambrian quartzite as resting unconformably upon granitoid gneiss at Clarksburg Mountain. In the granitoid gneiss is found a dike which has been decayed and washed out before the quartzite was deposited, leaving a fissure, which caused the beds of quartzite to thicken and sag and which contains at the bottom material derived from the dike. On Hoosac Mountain there is a core of granitoid gneiss, upon which rests unconformably at the axis coarse basal conglomerate with a sharp contact. In other places there is an apparent gradation between the metamorphosed conglomerate and the granitoid gneiss. This Cambrian quartzite conglomerate is found to vary laterally, in the legs of the fold, into completely crystalline white gneiss. The Cambrian formation, containing *Olenellus* fauna, mantles around the pre-Cambrian granitoid gneiss, and the whole mountain is an overturned fold.

SEARS,[66] in 1894, gives a description of each of the rocks of Essex County, Mass. These comprise plutonic rocks, volcanic rocks, Archean rocks, and various metamorphosed sedimentary rocks of Paleozoic age.

EMERSON,[67] in 1894, gives an outline of the geology of the Green Mountain region in Massachusetts. The Algonkian rocks comprise the Washington gneiss, Tyringham gneiss, East Lee gneiss, Hinsdale limestone, and Hinsdale gneiss. This series is the equivalent of the Stamford gneiss in Hoosac Mountain. The Algonkian rocks consist of firm, coarse gneisses which contain minerals and possess structures not formed in the later rocks; thick beds of coarse and highly crystalline limestones which contain many minerals rarely found in later limestones, as chondrodite, wernerite, dark pyroxene, and hornblende; and coarsely crystallized graphite; also considerable beds of pyrrhotite, magnetite, and graphite.

Because of the presence of the heavy beds of limestones, which were probably derived from shells and corals, we may assume that the whole series, except the hornblende gneiss of East Lee, was of sedimentary origin, but we know nothing of the limits of the sea in which they were spread. These rocks are overlain by the Cambrian Becket gneiss and Cheshire quartzite. As shown by the basal conglomerate at the Dalton Club House, these rocks rest unconformably upon the Algonkian.

Emerson,[68] in 1895, describes the geology of Old Hampshire County in Massachusetts, which includes the present counties of Franklin, Hampshire, and Hampden. On the western border of the Green Mountain area, as it crosses Massachusetts and overlooking the Housatonic Valley, is a series of pre-Cambrian outcrops, which are the oldest rocks of the State and the substratum on which the others rest. They consist of coarse gneisses, especially characterized by blue quartz and allanite, coarse porphyritic structure, and stretching; and great beds of highly crystalline limestone, containing chondrodite, coccolite, titanite, phlogopite, and wernerite. The most important of these limestone-beds are those of the Hoosac, the Hinsdale, and the Tyringham areas. The limestone beds connected with the two latter have caused the two most important passes through the range—the Westfield Valley and the East Lee-Farmington Valley.

On the pre-Cambrian rocks rest the Becket conglomerate gneisses, of Cambrian age, and above them a great series of sericite schists (the Hoosac schists, Rowe schists, Chester amphibolite, and Hawley schists), which are about contemporaneous with the Stockbridge limestone of the Housatonic Valley.

Emerson,[69] in 1898, describes the Algonkian rocks occurring in the southwest corner of the Holyoke quadrangle, Massachusetts, and in the area to the west. These are gneisses and limestones making up a series called the Washington gneiss. They are of sedimentary origin, with the possible exception of the hornblende gneiss of East Lee.

In general in western Massachusetts the Washington gneiss appears in oval areas surrounded by younger strata, the line of these ovals extending south from Hoosac Tunnel along the crest of the Green Mountain plateau. The gneiss enters the Holyoke quadrangle at the southwest corner and runs up across the town of Tolland, narrowing to a point near Black Pond.

Hobbs,[70] in 1906, summarizes the geology of southwestern Massachusetts and western Connecticut. There are peculiar difficulties in discriminating the pre-Cambrian from the Paleozoic which do not exist farther west. In the western area, the knowledge of which is summarized by Smith, near the base of the Paleozoic there is a well-recognized, conspicuous limestone formation, below which frequently is also a quartzite of varying thickness. This limestone is a good horizon marker, which makes the determination of an age succession for western Massachusetts, Connecticut, and New York comparatively easy. The limestone appears on the west side of Hoosac Mountain, but is not found east of that mountain. In this eastern area lenses of limestone occur sporadically, but it is not a continuous formation. The difficulties are further complicated by the fact that in the eastern area great masses of intrusive granite and other rocks of Paleozoic age are present, whereas in the western area few or no acidic Paleozoic intrusives are found. The absence of the key limestone horizons and the presence of the great masses of intrusives which have profoundly metamorphosed the rocks they entered make the discrimination between the Paleozoic and the pre-Paleozoic for the area under discussion a matter of extreme difficulty.

In the western part of the area under discussion—the immediate vicinity of the area where the base of the Cambrian is determined—there is a continuation of the gneisses which have been called Becket and Fordham and which are certainly pre-Cambrian. While this basal complex is represented by many widely differing types of gneiss, it has not been found possible to delimit separate formations within it. It has been definitely established that areas of schist and gneiss of Ordovician or later age occur in connection with the areas of the Becket gneiss without being separated by intervening Paleozoic quartzite or dolomite. In the northwestern portion of this area, or near the areas of Stockbridge (Cambro-Ordovician) dolomite, these belts of schist and gneiss more closely resemble the Berkshire or Hudson formation, and are believed to represent a phase of that formation. To the east of the principal core of pre-Cambrian, which occupies the northwestern half of Litchfield County, Conn., a different type of schist is encountered, which is characterized by filmy foliation planes covered by muscovite and bearing such metamorphic minerals as kyanite or garnet and staurolite of large dimensions. This formation, which occupies large areas to the east and southeast of the pre-Cambrian core, has not had its age definitely determined, but has been called Hartland schist, and it is believed to be of Paleozoic age.

The Becket gneiss is doubtless in large part igneous—a gray to white biotite granite gneiss—in which are found lenses, dikes, bosses, and irregular-shaped masses of amphibolite having the characteristics of an older intrusive, and regarded as such. The name Cornwall amphibolite has been applied to them. Within the pre-Cambrian core, also, are considerable areas of more recent intrusive granite, to which the name Thomaston granite has been applied. The same intrusive is found even more abundantly developed in the Hartland schist to the south and east, which latter rock has been so intricately injected by this granite, and locally so largely pegmatized, that it has been found impossible in mapping to delimit the sedimentary from the igneous material. These intricately injected areas, originally occupied in large part (though probably not wholly) by Hartland schist, occur especially in the neighborhood of Waterbury, and the name Waterbury gneiss has been applied to them.

Near the southern border of the pre-Cambrian core, or near the city of Litchfield, a hypersthene-bearing intrusive is found, which may be pre-Cambrian.

The structure of the area has been brought about in part by folding and in part by disjunctive processes. The folds in the gneiss are seldom simple folds, and are both longitudinal and transverse. The transverse folds have a variable trend, but on the average this direction runs with the extension of the formations, which is roughly northeast-southwest. The folds are seldom symmetrical, but usually overturned, sometimes eastward, at other times westward. Moreover, upon the large folds are superimposed folds of secondary or even tertiary magnitude which preserve in the main the same forms as the larger folds.

Upon this intricate complex of flexures has been superimposed a joint and fault system which has profoundly modified the areal distribution of formations and the location of their boundaries, and has impressed its influence profoundly upon the relief of the region. The characteristics of this elaborate joint and fault system have been determined by the study of favored or " key " localities, particularly, however, the fortuitously preserved areas of the later Newark formation.

SECTION 5. CONNECTICUT.

SUMMARY OF LITERATURE.

SILLIMAN,[71] in 1820, states that Primitive rocks occur in many places in the counties of New Haven and Litchfield. These rocks succeed each other with almost precisely the arrangement and succession laid down by Werner—clay slate, including beds of trap; mica slate; gneiss. Granite crowns the whole, although it occupies but a small extent compared with the gneiss and slaty rocks. As a whole the slates occupy the lowest and the granites and gneiss the highest situations.

MATHER,[72] in 1832, describes the succession from Killingly to Haddam as consisting of gneiss, granite, syenite, mica slate, hornblende slate, and granular quartz rock, the latter underlying thick strata of gneiss. Powerful veins of granite traverse the gneiss, while in other places the granite is found both in veins and in beds.

Mather,[73] in 1834, divides the rocks of Connecticut into gneiss, hornblende slate, mica slate, granular feldspar, granular quartz, syenite, granite, and limestone. The strata generally show themselves in long belts extending unbroken to a considerable distance. The thickness of the gneiss at one locality is not less than 10,000 feet. At Lebanon the gneiss surrounding a great part of the syenite dips so as apparently to pass under the latter rock. The syenite is not stratified, but the granite is partly stratified. The limestone occurs in beds 1 to 20 feet thick, embraced in the contorted gneiss in the northwestern part of Stonington.

Percival,[74] in 1842, divides the consolidated rocks of Connecticut into Primary, Secondary, and Trap rocks. The Primary rocks occupy the greater portion of the surface of the State and are divided into western and eastern sections. These Primary rocks are formed entirely of original materials, exhibiting no appearance of any fragment or remains of any anterior formation. The Trap rocks are chiefly connected with the Secondary rocks, although they also cut the Primary. These are regarded as intrusive and igneous. In describing the Primary rocks the term parallel is preferred to stratified, as simply expressing the arrangement of the minerals without implying any opinion as to the mode of formation. The western Primary system, which extends on the west and southwest into the State of New York and on the north into Massachusetts, is divided into a large number of local formations, including the classes mica slate, argillite, granite, calciferous schist, and limestone. The formations as a whole present a series of parallel ridges which have a general curvature with convexity toward the east. The central portion exhibits a series of granitic and micaceous alternations, which appear partly as elongated bands and partly as isolated nuclei, generally granitic, around which the more micaceous formations are concentrically arranged. The eastern Primary system is divided into several main groups, the rocks here including gneiss and micaceous and chloritic rocks. In one of the granitic formations the arrangement consists of a central nucleus of granite gneiss surrounded by narrow concentric rings of various characters. The zone immediately adjoining the granitic nucleus is characterized by the almost constant presence of anthophyllite. From the coarsest granites to the finest and most uniform schist the structure is characterized by a parallel arrangement of the mineral constituents. Continual alternations of series of granitic, micaceous, hornblendic, and various other formations were observed. The Trap rocks occurring in the Primary and Secondary formations are so nearly alike that they can not be separated, but in the Primary rocks there is no conformity between the Traps and the adjacent formations, such as prevails in the Secondary.

DANA,[75] in 1872, states that the quartzite of Canaan outcrops in six exposures, is unconformably below the limestone, and its jointing, uplifting, and consolidation took place before the latter was deposited.

See section 4 of this chapter for general summary of the geology of western Connecticut.

SECTION 6. RHODE ISLAND.

SUMMARY OF LITERATURE.

JACKSON,[76] in 1840, describes the older rocks of Rhode Island as Primary and Metamorphic. The Primary rocks are generally said to be rocks produced in the state of igneous fusion. Among these are placed granite, gneiss, and mica slate, although it is doubtful as to the manner in which these two latter rocks were formed. At Woonsocket a conglomerate passes into a mica slate. In general the contact between the gneiss, mica slate, and graywacke is sharp.

COZZENS,[77] in 1843, finds that the section on the island of Rhode Island is, from the base up, granite, serpentine, black slate, graywacke, black slate, Rhode Island coal, and diluvium.

JACKSON,[78] in 1859, maintains that the pebbles of the Newport conglomerates were mechanically formed by being rolled upon beaches, many of the distortions and indentations being accounted for in this way.

HITCHCOCK (C. H.),[79] in 1861, describes the lower rocks of the island of Aquidneck as, in ascending order, (1) talcoid schists, and conglomerates with red jasper pebbles; (2) Purgatory conglomerate, the pebbles of which are distorted; (3) mica schists, mica slates, conglomerates, sandstones, and grits west of Purgatory; (4) second conglomerate, and (5) coal measures.

DALE,[80] in 1883, gives detailed sections of many localities and descriptions of various places. The conglomerates are found in some cases to be highly metamorphic, the pebbles being unmistakably elongated and cut with scales of mica. The cleavage of the pebbles is regarded as partly due to their adhesion to the cement. The fractures with which they are cut are possibly due to wave motion or to the contraction of the conglomerate in cooling from a heated state. The chronological order and the thickness of the series are as follows, in ascending order:

Section of the older rocks of Rhode Island.

	Feet.
1. Hornblende schist alternating with mica schist	950
2. Chloritic schists and associated argillaceous and micaceous schists	500–750
3. Greenish, slaty conglomerate, with argillaceous and siliceous serpentine (conglomerate I)	500
4. Quartz and clay, aggregate	750

	Feet.
5. Argillaceous schists and associated slates, etc	600
6. Quartzite conglomerate, with grits and some argillaceous schist (conglomerate II)	750
7. Carbonaceous schists and shales, with argillaceous schists	500
8. Fine argillaceous conglomerate and grit	500
	5050–5300

Collie,[81] in 1895, describes the geology of Conanicut Island. The oldest rocks are a series of slates of unknown age, into which was intruded a mass of granite, porphyritic in character. This complex was exposed to weathering influences until a bed of débris lay upon its surface. This surface was depressed beneath the sea, and upon it was laid a great series of Carboniferous rocks. The complex was, therefore, the Carboniferous shore line. Into the Carboniferous rocks dikes were intruded, and both were folded and metamorphosed, and have in many places become schistose.

Woodworth,[82] in 1899, describes the Algonkian rocks in the lower portion of the Blackstone Valley and west of Providence, near the western margin of the Narragansett basin. Because of the typical development of the Algonkian rocks along Blackstone River between Woonsocket and Pawtucket, they are called the Blackstone series. This series is divided into the Cumberland quartzites; the Ashton schists, representing the finer sediments succeeding the deposition and partial erosion of the Cumberland quartzites, and in part probably igneous in origin; and the Smithfield limestone, apparently of sedimentary origin. As yet no facts have been discovered to show whether the limestones are of the same age or newer than the Ashton schists. The rocks of the Blackstone series are separated and penetrated by granitic intrusions or batholiths.

The Blackstone series is assigned to the Algonkian because of the difference in metamorphism of the Blackstone series and the Lower Cambrian strata, bearing *Olenellus* fauna, in North Attleboro. The Cambrian strata are little altered and lie in close proximity to the granite. Four miles west the Blackstone series is infolded with a similar granite and is much altered.

Kemp,[83] in 1899, gives a petrographic account of the pre-Cambrian and later granites of the Atlantic coast. He finds a striking predominance of biotite granites and gneisses.

Emerson and Perry,[84] in 1907, map and describe the green schists and associated granites and porphyries of Rhode Island. Pre-Cambrian gneiss occupies the southwestern part of the area mapped. It is probably the southward extension of the Northbridge gneiss extending southward from Southboro, Mass., and is called the Northbridge gneiss. It is overlain unconformably by Cambrian rocks.

SECTION 7. WESTERN NEW ENGLAND (GENERAL).

SUMMARY OF LITERATURE.

DANA,[85] in 1877, maintains that the conformable succession in Berkshire County, Mass., and in Vermont are the same, being (1) limestones and schists; (2) quartzites and schists; (3) quartzites and limestones; all conformable. The Taconic Range of Berkshire is probably Upper Trenton or Hudson River or Cincinnati. There are frequent abrupt transitions between the quartzite and the gneiss, which are believed to represent transitions from sand deposits to mud deposits in the old seas.

HITCHCOCK (C. H.),[86] in 1879, describes the Atlantic system as including the highlands of the Atlantic Ocean between Newfoundland and the Carolinas, comprising the Terranovan, confined to Newfoundland and Nova Scotia; the Montalban, with Green Mountain branch, in which are the White Mountains, and the Carolina, or Southern, which culminates in the Black Mountains. The rocks of the system were deposited in a Laurentian basin, with the Adirondacks on the west and the ancient gneisses of eastern Massachusetts on the east.

DANA,[87] in 1880, finds that the western and eastern halves of the Green Mountain area are one orological system, the rocks being similar, and all are of Lower Silurian age. With these belongs a part of the central mountain section. In view of these various considerations the evidence, although not yet beyond question, is manifestly strong for embracing the whole region between the Connecticut and the Hudson (and to an unascertained distance beyond) within the limits of the Green Mountain synclinorium.

DANA,[88] in 1884, finds that the schistose rocks constituting the Taconic Range grade, from north to south, from feebly crystalline argillite and hydromica schist to coarse-grained mica schist, garnetiferous and staurolitic. The eastern and western limestone belts blend with each other through the low regions, cross the Taconic line, and prove to be one formation. The limestone passes underneath the schist of the Taconic Range and outcrops on its east and west sides on opposite sides of the syncline. The limestones that constitute the lower part of the Taconic system contain fossils which show it to be Lower Silurian; hence the schists of the Taconic are later than Silurian age and probably belong to the Hudson River. The structure of the range is a compound syncline. Mount Washington is a syncline of the same kind, which dies out to the south with a multiplication of small subordinate flexures.

HITCHCOCK (C. H.),[89] in 1884, describes a number of geological sections across New Hampshire and Vermont, and correlates the rocks. The order and thickness of the crystalline formations are as follows, from above downward:

Section of the crystalline formations of New Hampshire and Vermont.

	Feet.
Calciferous mica schist and Coos group	12,000
Kearsarge group	1,300
Rockingham mica schist	6,000
Merrimac group	4,300
Huronian	12,000
Hornblende schist	1,500
Montalban	10,000
Lake Winnipiseogee (Green Mountain) gneiss	18,600
Bethlehem gneiss	6,300
Porphyritic gneiss	5,000
	77,000

The various groups are classified according to stratigraphic and not lithological reasons. Unlike rocks are never assumed to be identical. If a hornblende schist and a clay slate dip toward each other they are assumed to be of different age and to be separated by a fault. If a granitic rock shows foliation it is classed among the gneisses. The igneous rocks are devoid of marks of stratification. The Montalban is used to cover pre-Huronian and post or Upper Laurentian rocks. Huronian is used for convenience to designate the various schists of chloritic and argillitic aspect overlying the gneisses and inferior to the Cambrian so far as known. The Ascutney granite seems to have been erupted from below through one or more vents and spread over the rock adjacent, as is shown by the fact that in the valleys where erosion has cut into the base of the granite it is discovered that schists run under the igneous rock certainly for 300 feet. The mica schists show the presence of heat for a distance of 500 feet or more from the granite. The slates have been indurated so that they ring like iron when struck with a hammer. The limestones are sometimes calcined and even glazed. Veins enter both of the rocks from points several yards distant. The gneiss is not altered by the contact line. It would seem, therefore, as if we had here examples of contact phenomena, and only the later strata are affected, because the gneiss had been already made crystalline before the eruption of the granite.

Hitchcock (C. H.),[90] in 1886, divides the older rocks of Vermont into (1) granite (Devonian); (2) Eozoic gneiss; (3) Potsdam and later formations. In 3 are included the Georgia slates, the calciferous mica schist, etc. The Eozoic gneiss occurs in five areas and is believed to underlie the Potsdam or Quebec group. At Wallingford the quartzite is superimposed upon a gneiss, as shown by peculiar erosion. At Sunderland, East Wallingford, Ripton, and Bristol, Vt., and Clarksburg, Mass., the fossiliferous rocks contain pebbles of a peculiar blue quartz which is derived from the gneiss. The gneiss is a northward continuation of the Eozoic rocks of New Jersey and the Highlands of New York and of southern New England. In Maine the Cambrian, Huronian, and Taconic rocks are placed together, and also the Montalban and Laurentian. The granite and trap and altered slates are not placed in the stratigraphic column. The gneisses are regarded as older than either the Cambrian or the Huronian. The pre-Silurian rocks of New Hampshire are classified as follows:

Classification of the pre-Silurian rocks of New Hampshire.

Eozoic	Laurentian	Porphyritic gneiss.
	Atlantic	Bethlehem group.
		Lake Winnipiseogee gneiss.
		Montalban or White Mountain series.
		Franconia breccia.
	Labrador or Pemigewasset	Conway granite.
		Albany granite.
		Chocorua granite.
		Ossipyte.
		Compact feldspar.
		Exeter syenites.
	Huronian	Lisbon group.
		Lyman group.
		Auriferous conglomerate.
Paleozoic	Cambrian	Rockingham schists.
		Calciferous mica schist.
		Coos group.
		Clay slates.
		Mount Mote conglomerate.

The name Atlantic system is proposed to cover all the rocks along the Atlantic coast from Maine to Alabama, being regarded posterior in time to the Laurentian but anterior to the Cambrian and later formations.

Walcott,[91] in 1888, in a consideration of the Taconic, places the western core of the Green Mountains as pre-Cambrian, the bounding line being at a considerable but varying distance east of Rutland, Middlebury, Burlington, and St. Albans. All of the rocks of western Massachusetts are regarded as Cambrian or post-Cambrian, including the Stockbridge limestone, the granular quartz rock, the magnesian slate, Sparry limestone, and Taconic slate. In northwestern Connecticut is an area of pre-Cambrian rocks which is surrounded by quartzite referred to the Georgia formation.

Van Hise,[92] in 1901, visited the metamorphic crystalline areas of southern Vermont, western and central Massachusetts, and western Connecticut. He finds that though nearly all the members of the crystalline series of this region have locally been so profoundly metamorphosed that the determination of their age and stratigraphic relations at such places is extremely difficult, yet as a whole there can be distinguished two unconformable series—an older completely crystalline basement, upon which later sediments have been deposited. Thus in the Hoosac Mountain portion of the Taconic quadrangle it is found that the white gneiss, which had previously been considered as belonging with the Cambrian Vermont formation, is pre-Cambrian, that there is here no transition between the pre-Cambrian igneous and the Cambrian sedimentary gneiss, but that the pre-Cambrian white gneiss can be lithologically distinguished from the sedimentary series above, and that the unconformity between the two is further shown by the frequent presence of conglomerate in the base of the overlying Vermont quartzite.

It was further found that much of the series which had previously been mapped as Becket gneiss of Cambrian age, consisting of schistose granite, interlaminated biotitic and amphibolitic schist, and locally including quartzite and quartz schist, should be regarded as an older basement of pre-Cambrian age, upon which the later sediments were deposited, and that where the Becket has been mapped as containing rocks of sedimentary origin it should be separated into two unconformable series. There is thus present in this region a lower series of pre-Cambrian age, comprising the complex of schistose granite and gneiss, pegmatite, and biotitic-amphibolitic schist, which are predominantly of igneous origin, and unconformably above this an upper (Palezoic) series consisting predominantly of rocks of sedimentary origin. Both series have been injected by later basic and acidic igneous rocks and together have been subjected to severe dynamic movement. The upper series is locally so metamorphosed that it is with difficulty discriminated from the underlying pre-Cambrian.

A striking instance of local extreme metamorphism of formations of comparatively late age is found at Worcester, Mass. Here there are mica schists and argillites of Carboniferous age which by deep-seated metamorphism have been altered completely to crystalline schists and which are cut in a most intricate manner by igneous intrusions, making a complex very similar in appearance to that characteristic of the pre-Cambrian. Another instance of the similarity of the metamorphosed Paleozoic formations to certain phases of the pre-Cambrian is found at Hoosac Mountain, Massachusetts. The graywacke schist member of the Vermont (Cambrian) formation is here locally so homogeneous in character that further metamorphism of it would produce a gneiss which could not be distinguished from a gneiss of igneous origin, while the quartzite member of this formation has also locally the thoroughly crystalline character of pre-Cambrian quartzites.

The normal succession for large areas in western New England appears to be: (1) Pre-Cambrian basement, predominantly of igneous origin, upon which unconformably rest (2) quartzite and quartz schist, (3) limestone, (4) quartz-mica-feldspar schist. This succession is but rarely completely present. Locally each member of the upper series is found to rest unconformably upon the pre-Cambrian core. This distribution would be in accordance with the view that the pre-Cambrian shore was to the east, and thus each higher member of the sedimentary series extended by overlap beyond the lower formations and was deposited directly on the pre-Cambrian basement.

HOBBS,[93] in 1903 and 1904, concludes that the crystalline rocks of southwestern New England have been deformed by a system of joints and faults of post-Newark age superimposed upon older structures which appear to be largely due to folding. He concludes further that the crystalline and later rocks of the Atlantic coast in general show lineaments suggesting regular sets of faults in a nearly meridional series and in two other series which make nearly equal angles with this direction. Other lineaments which more closely approach the equatorial direction vary more from one another and are both numerically less important and less strikingly brought out.

SECTION 8. SUMMARY OF PRESENT KNOWLEDGE OF NEW ENGLAND.

The following summary has been prepared by George Otis Smith:

In the first edition of this bulletin the generalization was made that large areas of rocks in New England commonly regarded as pre-Cambrian were proving to be Cambrian or post-Cambrian in age. This statement is well substantiated by the results that have come with the progress of systematic work during the last decade. Not only has the post-Algonkian age of many schists, gneisses, and granites been proved, but the line between the pre-Cambrian and the younger formations has been accurately determined in certain areas and to some extent a pre-Cambrian succession of formations has been established.

The earlier work on the subject of the origin of crystalline schists and their correlation with known clastic formations was a necessary preliminary to the true interpretation of New England geology. The later work on the crystalline rocks of this province has resulted, first of all, in the recognition of the post-Algonkian age and the clastic nature of large areas of metamorphic schists and gneisses, but there has also been a great advance in the determination of the post-Algonkian age and the intrusive character of many masses, small and large, of granite gneiss and granite long held to be of pre-Cambrian age. The adherence of New England geologists to the theory of a metamorphic origin for granite long delayed the proper comprehension of the true significance of the large bodies of granite and granite gneiss and their importance as structural elements in this province. Even the latest revision of the systematic work in western Massachusetts affords evidence of this tardy recognition of the igneous rather than metamorphic character of a granite gneiss the pre-Cambrian age of which is now established.

In Maine and New Hampshire the amount of systematic work done during the last decade has been insufficient to allow much revision of the results of the earlier surveys. Recent mapping on the Maine coast has shown the presence of several metamorphic formations, which represent old sediments and ancient volcanics, mostly of Paleozoic age. The oldest of the crystalline schists in the vicinity of Penobscot Bay is a green quartz-mica schist, which may be of pre-Cambrian age. It is noteworthy that in this area and elsewhere on the Maine coast, as far as known, the granite is of late Paleozoic age and is usually the youngest of the rocks present. It is possible, however, that the granite of the mountainous portion of western Maine is older. In the upper valley of Androscoggin River the granite is characterized by a well-developed gneissoid texture, with crushing and banding of the constituent minerals, and thus appears quite distinct from the granite known to be of Paleozoic age.

In New Hampshire the progress in the study of the crystalline rocks may best be summarized by quoting two recent statements by C. H. Hitchcock.[a]

> A long list of what were formerly called metamorphic schists may now be classed as eruptive igneous rocks, such as the porphyritic granite, Bethlehem granite, Lake gneiss, diorites, and protogenes, to say nothing of what has always been recognized as granite and diabase. The periods of their extrusion were evidently middle or late Paleozoic.
>
> The general results of our studies tend to restrict the areas of the more ancient rocks and to increase those representing the Paleozoic groups in the adjoining regions of northern New England.

In southern Vermont and western Massachusetts the systematic areal work of Wolff and Emerson has resulted in valuable contributions to the knowledge of the pre-Cambrian of the Green Mountain range. In southern Vermont Wolff describes the axis of this range as composed of a gneissic complex. The many lithologic types include coarse reddish and white gneisses, fine-grained, bluish-gray garnetiferous gneiss, biotitic schist, pegmatite, amphibolite, and graphite gneiss. The constituent minerals and the structures are largely secondary and are referred to pressure metamorphism. Another pre-Cambrian gneiss occurring in this area is the Stamford gneiss, which is best known as forming the core of Hoosac Mountain. This rock

[a] Bull. Geol. Soc. America, vol. 15, 1904, pp. 479–480.

where least affected by dynamic metamorphism is a coarse gneiss composed of white microcline and blue quartz, with accessory biotite, zircon, apatite, and magnetite. This gneiss is believed to be intrusive in the gneissic complex. Later intrusives known to be of pre-Cambrian age occur in narrow dikes, cutting across the foliation of the gneisses, and appear to represent metamorphosed diabase, while another intrusive, probably of pre-Cambrian age, is a peridotite.

Farther south along the Green Mountain range Emerson has determined the pre-Cambrian sequence with considerable detail. Four formations are distinguished; these are, in ascending sequence, the Hinsdale gneiss, the Colesbrook limestone, the Washington gneiss, and the Becket gneiss. Two of these, the limestone and the Washington gneiss, are plainly of sedimentary origin; the first may include some igneous material, and the last is an igneous rock intrusive in the others. The Hinsdale gneiss is in places an evenly banded hornblende gneiss, but more commonly is a highly contorted black or rusty mica schist, and the presence of graphite in flakes is characteristic for this rock. The Colesbrook limestone is in part a very pure, coarse, white marble, usually containing scattered flakes of graphite. In places this rock is full of lime silicates, and these increase in abundance until in some localities the marble is largely represented by these metamorphic minerals. The Washington gneiss approaches a quartzite in composition, but differs somewhat in texture and general appearance. This formation is largely made up of stringers and beds of blue opalescent quartz.

In the earlier study of this region the Becket gneiss was believed to include some conglomeratic beds, and these together with the resemblance of much of the gneiss to the white gneiss forming the base of the Cambrian on Hoosac Mountain were taken as indicative of the metamorphic origin of this granitic gneiss. On this basis the gneiss was correlated with the Vermont quartzite and regarded as of Cambrian age. Later it was found possible to discriminate between the metamorphosed sedimentary rock and the older granite, so that the Becket gneiss is now believed to be a granite intrusive in the other pre-Cambrian rocks, although it is itself more or less gneissoid. It is medium to fine grained and contains quartz, oligoclase, microcline, muscovite, and biotite. The Tyringham and Lee gneisses, earlier described as separate pre-Cambrian rocks, are now considered facies of the Becket gneiss; the Tyringham gneiss is characterized by a fibrous or " pencil " texture and represents an exceptional phase of the metamorphism of the Becket gneiss, while the Lee gneiss is the border facies or contact phase of the granite. The Becket granite has included large masses of the Colesbrook, as well as of the other pre-Cambrian formations.

In western Rhode Island there is an area of pre-Cambrian gneiss, which extends westward into Connecticut and northward as far as Southboro, Mass. This rock is described by Emerson as a medium to coarse-grained light-colored gneiss. In texture it is granitoid, sometimes porphyritic, but more often presents a mashed or stretched facies. This Northbridge gneiss of Emerson is to be distinguished, however, from the porphyritic granite gneiss which borders the Cambrian rocks on the south and east side of the Narragansett basin, since that granite is probably intrusive in the Cambrian strata.

The metamorphosed sediments termed the "Blackstone series" by Woodworth and assigned by him to the Algonkian are now believed by Emerson to be of Cambrian age.

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[15] Significance of oval granitoid areas in the Lower Laurentian, by C. H. Hitchcock. Bull. Geol. Soc. America, vol. 1, 1890, pp. 557–558 (abstract). Discussion by G. H. Williams.

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CHAPTER X.

ADIRONDACK MOUNTAINS, SOUTHEASTERN NEW YORK, AND NEW JERSEY.

SECTION 1. ADIRONDACK MOUNTAINS.

SUMMARY OF LITERATURE.

JESSUP,[1] in 1821, describes rocks of the Primitive class, including trap, syenite, and carbonate of lime, in Essex County, in the vicinity of Lakes George and Champlain.

EATON,[2] in 1824, describes the rocks adjoining the Erie Canal. Among the Primitive rocks are placed granite, gneiss, hornblende rock, mica slate, talcose rock, granular quartz, granular lime rock, sparry lime rock, and Primitive argillite, which are described as occurring at numerous localities. There are two Primitive districts—one in southeastern New York and another west of Lake Champlain, called Macomb Mountains.

EMMONS (E.),[3] in 1837, describes granite and gneiss as having a widespread occurrence in the northeastern part of the State. The granitic nucleus of Essex County is traversed by dikes of greenstone of igneous origin, and the granite is considered to have the same genesis. Gneiss and hornblende and granular limestone are classed together as Primitive rocks and regarded as absolutely of the same age. Above the Primitive rocks is a Transition sandstone, superimposed upon which is a Transition limestone.

CONRAD,[4] in 1837, describes ridges of gneiss at the base of the Mohawk Valley which are regarded as a prolongation of the northern Primary chain. Upon the gneiss is calcareous sandstone.

EMMONS (E.),[5] in 1838, states that in St. Lawrence and Essex counties are found Primitive rocks. The stratification of the gneiss is often obscure and its texture confusedly crystalline. Subordinate to it and mingled with it is granite, which occurs in beds and protruded masses in the forms of veins and in overlying masses analogous to lava currents and greenstones. In St. Lawrence County is a widespread granite composed of labradorite, feldspar, and hypersthene, which is traversed by dikes of greenstone, amphibolite, syenite, and porphyry. Associated with the gneiss and limestone are numerous beds of magnetite and hematite. The Transition rocks of Essex County, such as limestones and shales, are cut by dikes and veins.

The Primitive limestone is always coarse, crystalline, and friable. It occurs in most intricate and curious relations to the granite and hypersthene rock, many of its areas being in veinlike form. This fact, combined with the presence of foliated plumbago and the induration of sandstone when in contact with the limestone, leads to the conclusion that it is of igneous origin.

VANUXEM,[6] in 1838, finds Primitive rocks in Montgomery, Herkimer, and Oneida counties.

EMMONS (E.),[7] in 1839, describes Primitive rocks in Hamilton, Clinton, and Warren counties. The Primitive rocks are gneiss, hornblende, limestone, and serpentine. The limestone and serpentine occur in irregular veins or beds, which are sometimes analogous to the greenstone dikes so prevalent in the hypersthene rocks.

EMMONS (E.),[8] in 1840, states that magnetic iron ore occurs associated with granite, gneiss, and hypersthene rock in veins which are regarded as of igneous origin. The specular oxide occurs in two horizons, the first associated with the Primary limestone, the second with gneiss or some other Primary rock beneath it.

VANUXEM,[9] in 1840, states that the Primary rocks, which are defined as earlier than any which bear organic bodies in Lewis County, consist mostly of granite and gneiss, but are associated with amphibolite or hornblende, forming syenite and hornblende rock. The Potsdam sandstone rests unconformably upon the Primary rocks. There is a great contrast between the two classes, the latter presenting a disturbed appearance, exhibiting high grades of inclination, while those of the Transition are like the deposits of tranquil waters.

MATHER,[10] in 1841, states that the Primitive rocks occupy two-fifths of Saratoga and one-fifth of Washington County, being mostly gneiss and granite, although coarsely crystalline white limestone containing plumbago, augite, and hornblende is a common rock.

EMMONS (E.),[11] in 1841, mentions Primary limestone at Lake Janet, gneiss at Long Lake, and hypersthene rock on Racket River.

EMMONS (E.),[12] in 1842, gives a report on the entire Adirondack region. The older rocks are classified under Primary and Transition. There are few transitions from the Primary into the sedimentary rocks. There are, however, many transitions among the Primary masses themselves, and often intermediate series are found which are with difficulty placed under appropriate names. The Primary rocks are divided into unstratified, stratified, and subordinate. Among the unstratified rocks are included granite, hypersthene rock, Primitive limestone, serpentine, and rensellaerite. The stratified rocks include gneiss, hornblende, syenite, and talc or steatite; the subordinate rocks include porphyry, trap, and magnetic and specular oxides of iron.

The granites occupy a comparatively small extent in the region, being in limited patches of irregular appearance. One of the largest beds of granite is about 6 miles long. In one place granite and limestone are somewhat intermingled. The hypersthene rock occupies a triangular area, to which it is almost wholly confined, but it constitutes almost the entire county of Essex, with the exception of a belt a few miles in width along the shore of the lake. Under Primitive limestone is included a coarse, crystalline mass, readily recognized as a mineralogical species, but as a rock not holding a definite place in the Primary series. This rock is believed to be unstratified and of igneous origin, as is shown by its occurrence in dikelike forms and its association with eruptive rocks, the embedded minerals being of such a character as would be produced by metamorphism. Also limestone produces a metamorphosing effect upon the minerals embedded in it, is always without stratification, often underlies granite, and is so intimately associated with it as to make it probable that the two have a common origin. Serpentine intimately associated with the limestone has an origin common with it.

The stratified rocks have a much wider occurrence than the massive ones. Of these gneiss is by far the most important. Syenite is applied to a stratified rock composed of feldspar and hornblende. It often occurs injected in the form of dikes and associated with beds of iron ore, and is in part an igneous rock. Trap includes dark-colored igneous rocks, which cut the various other Primitive formations. These are compared with mineral veins, and because the former is eruptive it is concluded that the latter probably have a similar origin. Porphyry is also found in igneous forms. Magnetic and specular oxides of iron occur as masses and as veins. They are sometimes apparently interstratified with rocks with which they are associated, but often also break across the strata. In their mode of occurrence they resemble trap, greenstone, and porphyry, and are therefore regarded as of igneous origin. Between the Primary and Transition systems is the Taconic system.

Vanuxem,[13] in 1842, describes the Primary system as occurring in the northern parts of Montgomery and Herkimer counties, the northeast corner of Oneida County, and the whole of Lewis County east of Black River. This system consists wholly of granite and gneiss, with which is associated a small quantity of limestone and iron ore. Primary rocks occur isolated in the New York system—at the Noses on the Mohawk, at the little falls of the Mohawk, and at Middleville. With the Taconic system are placed a lamellar white crystalline limestone, with specular iron ore and compact red iron ore and plumbaceous rocks in Lewis County

Macfarlane,[14] in 1865, describes the rocks in the neighborhood of Rossie as belonging almost exclusively to the Laurentian formation, which is here and there unconformably overlain by patches of Potsdam sandstone. The rocks here found comprise micaceous and hornblendic gneiss, mica schist, gneiss granite, granite, tourmaline rock, coarsely granular saccharoidal crystalline limestone, and diorite. The strata are in an almost vertical position.

LEEDS,[15] in 1878, describes the rocks of the Adirondacks. They are found to be stratified rocks which belong in the Norian system, and are composed of hypersthene, diallage, and labradorite with menaccanite.

HUNT,[16] in 1883, describes coarsely crystalline limestones in the highly inclined Laurentian gneisses near Port Henry, in which are inclosed irregular masses and layers of the adjacent gneiss. Although regarded by Emmons and Mather as eruptive and by another eminent geologist as evidence that the crystalline limestone unconformably overlies the gneiss, it is believed to be a great calcareous vein stone. The Norian, massive, bedded, labradoritic rocks are well displayed between Westport and Port Kent.

HALL (C. E.),[17] in 1885, states that between the limestones and the magnetic ore series or lower members of the Laurentian there is an undoubted unconformity; but the relations of the Labrador series to the limestone are not clear. In ascending order are the Lower Laurentian, or magnetic iron-ore series; the Laurentian sulphur ore series; the limestones; and the Labrador series, or Upper Laurentian, with its titanic iron ores. The relations of the sulphur ores and limestone series are still undetermined. Between Fort Ann and South Bay, along the east side of the valley, the Silurian limestones lie against and apparently dip under the crystalline rocks of the Laurentian. The Potsdam sandstone, resting on the crystalline rocks of the valley, dips to the east under the Silurian limestones.

BRITTON,[18] in 1886, states that a schistose series of crystalline rocks occurs in the Adirondacks. It consists of schistose gneiss, mica schist, and hornblende schist, and occurs north of Harrietstown and near the north end of the Lower Saranac Lake. Norite occurs at Miller's hotel, about a mile distant.

JULIEN,[19] in 1886, states that the borders of the Adirondack region consist very largely of thinly bedded gneisses, especially toward the east.

PUMPELLY, WALCOTT, and VAN HISE,[20] in 1890, under the guidance of Walcott, who had seen most of the localities before, examined various districts on the eastern side of the Adirondacks from Fort Ann, south of Whitehall, to Westport. The peripheral area of this part of the Adirondacks was found to be a great series of laminated rocks, consisting for the most part of white and red, regularly laminated gneisses, very frequently garnetiferous, and in lesser quantity of garnetiferous quartz schist, crystalline limestone, graphitic gneiss, and beds of magnetic iron ore, dipping as a whole at a rather flat angle toward the east and southeast. The garnetiferous quartz schists were found in rather persistent beds. A graphite mine in the neighborhood of Hague is a layer of very graphitic gneiss, comparable, as said by Walcott, to a coal seam in an ordinary bedded succession. Scales of graphite are uniformly disseminated through the coarsely crystalline limestone, the amount often being very considerable. Below the crystalline limestone is a coarse black hornblendic gneiss, the contacts between it and the limestone being of a most extraordinary character. The plane between them is one of great irregularity. In the limestone are contained numerous fragments and even great bowlders of the gneiss, and for a distance of some feet away from the contact are numerous crystals of feldspar. The appearance is such as to suggest very strongly that here is an unconformable contact, the limestone being deposited along an encroaching shore line. The phenomena are, however, probably due to the breaking up of layers of gneiss and veins of pegmatite by powerful dynamic movements. In passing from Westport within a short distance appeared coarse gabbro, which continued as far as the region was penetrated, nearly to Mount Marcy. This rock in the interior is generally massive, but on its outer border grades into a regularly laminated rock, resembling in exposure very closely the laminated gneisses. The whole is, however, clearly an eruptive rock. Granite was seen locally associated with the gneisses.

Williams and Van Hise,[21] in 1890, examined the western side of the Adirondacks. Just as on its eastern side, there was found a peripheral succession of regularly laminated gneisses and crystalline limestones of great thickness. The latter is particularly well seen in the neighborhood of Gouverneur. The contacts between the limestones and the lower gneiss were found to be almost identical with those on the eastern side of the mountains, but the appearance here strongly suggests that the relations have been produced by interior movements of the rocks, the irregular contact surface being a contorted one as a result of folding, and the contained fragments broken off and included in the limestone by means of dynamic action. The interior of the Adirondacks was here found to consist of gabbro, in every respect like that on the east side of the mountains.

In passing inward from the gneissic series the gabbro is found first in small quantity, then in more and more abundance, until finally it becomes predominant. At Bonaparte Lake was found a contact of the gabbro with the limestone which showed all the characteristics of an intrusive rock, the limestone giving evidence of contact action. There were found, both in the limestone and in the gabbro areas, smaller areas of coarse red granite.

As a result of the reconnaissance it was concluded as probable that the Adirondacks core is an eruptive basic rock, which has been upthrust and intruded within the gneissic series. Because of the character of the gneissic series, containing quartz schist, graphitic schist, and crystalline limestone, including graphite, it is regarded as having been originally clastic. Its present crystalline character and quaquaversal arrangement are doubtless due in part to the intrusion of the gabbro and the consequent dynamic effects. It thus appears that there is in this region a great bedded succession which belongs to the Algonkian system. The lowest coarse-grained gneiss inferior to the limestone perhaps belongs to a still earlier series, but this is a point upon which closer studies are needed.

Smyth (C. H.),[22] in 1893, describes the rocks near Gouverneur, N. Y., as consisting of gneiss, granite, limestone, and sandstone, with small amounts of associated schists. The gneiss is the oldest rock of the region, underlying the other formations. It sometimes grades into a true granite, the passage being gradual. The two are regarded as different phases of the same rock, the granite being either an unchanged remnant of a plutonic mass from which the gneiss is derived or the result of fusion of the gneiss. Evidence of unconformity between the beds of the limestone and the foliation of the gneiss was found in two localities, and was indicated in several others; there is no evidence of irruptive contacts between the gneiss and the limestone; the gneiss shows no evidence of sedimentary origin; therefore the simplest hypothesis, but requiring more proof, is that the gneiss is an eroded metamorphosed plutonic rock, upon which the limestone was deposited. The marble is coarsely crystalline, and in age is next to the gneiss. Near the base of the limestone, and interbedded with it, are peculiar schistose rocks, which, though completely crystalline and resembling igneous rocks in composition, their field relations indicate to be of sedimentary origin. Near Gouverneur an outcrop of limestone contains abundant fragments of black schist, scattered through the limestone in a most irregular manner, and making up, perhaps, one-third of the rock. This and other outcrops show that the schist fragments are remains of once continuous schist layers which have been completely shattered in the course of metamorphism, since between the continuous belts of schist and the Gouverneur locality there is every possible gradation. While the schists show the effects of foldings, contortions, stretchings, and shattering, the limestone shows no traces of them, appearing to have been a plastic mass in which the schists moved with considerable freedom. The conspicuous result of metamorphism in the limestone is crystallization. In the limestones are also pegmatitic veins, which have been much shattered by the dynamic action, reducing them to small lumps of quartz and feldspar, scattered through the limestone. So far as observed the pegmatite yields to strain only by fracturing, not showing preliminary contortions, so general in the schistose layers.

In the southern part of the area examined is a granite which does not grade into gneiss and which breaks through the limestone, causing great disturbance in strike and dip, inclosing masses of the rock many feet in diameter, and metamorphosing this rock to some extent. The sandstone at Gouverneur was found in direct contact with the limestone. Here it appears that the limestone surface was subjected to erosion before the sandstone was deposited upon it. In confirmation of this are seen narrow irregular cracks extending several feet into the limestone, which have been filled with sandstone. The limestone was evidently completely lithified when the sandstone was deposited and sifted into it, and this implies discordance. This unconformity proves that the limestone is older than the upper Cambrian, the data being wanting for any more definite determination of its age. The metamorphism of the rocks of the limestone-bearing series occurred before upper Cambrian time, but the sandstone is metamorphosed, and this metamorphism must therefore belong to post-Potsdam time.

SMYTH,[23] in 1893, describes the rocks of Gouverneur, N. Y. The gneiss gives evidence of mechanical deformation in the shattering of the quartz and feldspar particles. Within the feldspar, along the cracks, microperthite has developed which does not show any dynamic action. The granite is much later than the gneiss, but, like it, has to some extent suffered from dynamic action. In general it is massive, or nearly so, but there are zones of shearing where granulite and gneiss have developed. Also in one portion there is a dark rock approaching a diorite, into which the granite grades, but this is regarded as a basic segregation from the original magma. The crystalline limestone is rather uniform in character, but where intruded by the granite it is more coarsely crystalline and various metamorphic minerals have developed. Near the base of the limestone is a pyroxenic rock which is schistose, highly contorted, and of somewhat doubtful origin, in the field being regarded as sedimentary, and under the microscope having an appearance which suggests igneous origin. In this pyroxenic gneiss occasionally scapolite is found. The Potsdam is a pure vitreous quartzite, indurated by the process of cementation.

NASON,[24] in 1893, describes the gneissic rocks bearing iron ore in the Adirondack region as precisely like the Mount Hope type of rock, bearing the New Jersey magnetites, and it is thought that the two are probably contemporaneous bedded deposits. These gneissic ores are nontitaniferous and are to be discriminated from the titaniferous iron ores which are associated with the labradorite rocks or norites of the region. These in occurrence and association are wholly distinct from the ores belonging in the gneisses.

KEMP and MARSTERS,[25] in 1893, give the field occurrence and microscopical characters of the trap dikes of the Lake Champlain region.

The dikes are found to be bostonites, diabases, camptonites, fourchite, and monchiquite.

CUSHING,[26] in 1894, mentions pre-Cambrian rocks in Saranac Township and Beekmantown, N. Y. These comprise gneisses and gabbro, upon which the Cambrian rests unconformably.

SMYTH (C. H.),[27] in 1894, describes a group of diabase dikes as breaking through the granite, gneiss, and quartzite in the vicinity of the village of Gannanoque, Ontario, the whole being overlain by Potsdam sandstone.

WHITE,[28] in 1894, describes and maps the geology of Essex and Willsboro Townships, Essex County, N. Y. The Archean rocks of the townships comprise the following: (1) Labradorite rocks, gabbros, norites, and anorthosites, occupying the western half of the area, west of Boquet River; (2) the metamorphic crystalline limestones and ophicalcites in the northeastern part of the area on Willsboro Bay, and in the southeastern part of the area on the ridge of Split Rock Point; (3) gneisses and granites, chiefly on Split Rock Point. Following Adams,[a] White classes all these rocks as Norian or Upper Laurentian.

KEMP,[29] in 1894, describes the gabbros of the western shore of Lake Champlain. The rocks occurring in this area comprise (1) gneisses, (2) crystalline limestones, including black hornblendic and pyroxenic schists and gneisses, and (3) anorthosites, including gabbro proper, olivine gabbros, and norites. The anorthosites over large areas have been profoundly affected by dynamic action, and in many places now have a gneissic structure. In the anorthosites at various places, and particularly at Split Rock Mountains, forming the more basic crystallization from the original magma, are lean, titaniferous magnetites which have been mined as iron ores. At the contacts of the gabbro and limestone the latter rock has been bent by dynamic movements; various silicates have developed within it, among which are scapolite, hornblende, pyroxene, and titanite. The limestone is also coarsely crystalline. Since the intrusion of the gabbro the limestone has been subjected to dynamic movements, and exhibits strongly the characteristic plasticity of this rock under stress.

SMYTH (C. H.),[30] in 1894, gives a petrographical description of the gabbros of the southwestern Adirondack region, and of black hornblende gneiss which occurs in the same area. The most altered form of the gabbro is very similar to the hornblende gneiss, and it is suggested that the latter is but an extremely metamorphosed phase of the former.

KEMP,[31] in 1894, describes the geology of Essex County, N. Y. The pre-Cambrian succession in this county is as follows: (1) A gneissic

[a] Adams, F. D., Ueber das Norian oder Ober-Laurentian von Canada: Neues Jahrb., Beil. Band 8, p. 423.

series consisting of red and gray orthoclase gneisses, usually laminated, but at times rather massive. In these gneisses are the workable iron ores of the Adirondacks. (2) Apparently resting on 1, a series of crystalline limestones, ophicalcites, black hornblendic pyroxenic schists, and thinly laminated garnetiferous gneiss. Pegmatite veins are a frequent associate of these rocks. (3) A series of rocks of the gabbro family, ranging from aggregates of labradorite through varieties with increasing amounts of bisilicates to basic olivine gabbros. The gabbros vary from massive to gneissoid rocks which are difficult to discriminate from some of the gneisses of series 1. These rocks contain the titaniferous iron ores. They are intrusive in series 1 and 2. Resting unconformably upon 1, 2, and 3 is the Potsdam sandstone.

Smyth (C. H., jr.),[32] in 1895, describes the crystalline limestones and associated rocks of the northwestern Adirondack region. The limestones, instead of being in limited patches as in the eastern part of the Adirondacks, are in extended belts many square miles in area. The limestone belt running through the townships of Rossie and Gouverneur has been traced more than 20 miles along the strike, while the average width is perhaps 6 miles. A narrower belt extends across Fowler into Edwards Township. A third belt crosses the townships of Diana and Pitcairn, with an average width of 2 or 3 miles. In addition to these belts, numerous scattered patches have been noted in the western Adirondacks.

The limestones are highly crystalline, coarse, light-gray or white rocks, containing silicates in separate crystals or segregated in lumps. Among these phlogopite, graphite, pyroxene, and tourmaline are most common. The limestone is usually so massive that it is difficult to ascertain the strike and dip with any accuracy. When observable the strike is generally northeast and the dip northwest, though exceptions are common. Garnetiferous and micaceous gneisses and pyroxenic and hornblendic gneisses are intimately associated with the limestone. The former are in some cases distinctly interbedded with the limestone, while many of the latter have the appearance of interbedded members, and others closely resemble somewhat modified intrusions. Wherever the hornblendic and pyroxenic gneisses appear they show a great amount of crumpling and crushing, which goes from slight plication to elaborate contortion or to crushing into angular fragments in a paste of limestone, thus producing remarkable breccias. In all of these cases the limestone shows little or no sign of structural change, having the appearance of a plastic mass in which the contained layers could be twisted to any extent. It therefore follows that the massive and undisturbed appearance of the limestone, when free from gneissic layers, does not show that it has not been subjected to intense mechanical strain, as subsequent to this it may have recrystallized.

This limestone series has a marked resemblance to the Grenville series, but because it is difficult to establish such an equivalency it is suggested that it be called the Oswegatchie series. The areas between the belts of limestone are occupied by gneiss, whose origin and relations to the limestone series are doubtful. The limestone series can hardly be regarded as of other than sedimentary origin. In many cases these gneisses adjacent to the limestone closely resemble the interbedded garnetiferous gneisses, and doubtless should be regarded as members of the limestone series. These varieties pass gradually into more nearly massive gneisses of feldspathic aspect, and in a number of cases these are in direct contact with the limestone. A part of these gneisses at least are of igneous origin, as is shown by their contact relations, but whether this explanation is applicable to all of them it is impossible to show. Intrusive in the limestone series are granite, diorite, gabbro, and diabase. Their intrusive nature is shown by all the usual phenomena characteristic of such relations.

The gabbro is most variable in its petrographical character. At one place it is in sharp contact with the granite. The relations of the gabbro to the gneiss are difficult to unravel. At Natural Bridge is found the normal gabbro, and in passing toward the red gneiss it appears to grade into it, and the two may be different facies of the same eruptive mass. The contact zones between the limestone and the intrusive gabbro are narrow and sharply defined, and this fact, combined with the great mechanical disturbances of the limestone series, justifies the conclusion that its metamorphism is largely dynamic.

Kemp,[33] in 1895, describes the titaniferous iron ores of the Adirondacks. These occur in the gabbros. The ores are regarded as segregations from the igneous magma formed during the process of cooling and crystallization.

Kemp,[34] in 1895, describes the crystalline limestones, ophicalcites, and associated schists of the eastern Adirondacks. Study of the region seems to corroborate the conception of the Adirondack Mountains which has been sketched by Van Hise—a central intrusion of igneous rocks, with a fringing rim of older gneisses, schists, and limestones. A closer approximation would be to regard the intrusions as in several more or less parallel ranges, with remnants of the other rocks in the valleys between them and on the flanks.

The limestones and the associated rocks always occur in depressions, the resistant ridges consisting of the harder gneiss or anorthosite. The former constitute sections as broad as 1,000 feet, in which the limestone strata are, however, less than half, and the true thickness of which is difficult to determine because of the varying dips, the schistosity, and the possibility of faults. The white limestones are coarsely crystalline, usually graphitic, and often include silicates, from little scales to large bunches. At Keene Center, in the heart of the Adirondacks, is a white limestone and schist belt which contains magnetic iron ore and is overlain by garnetiferous and pyroxenic schists or pyroxenic granulite, the relations indicating that the latter is a gneissic rock interbedded with the limestone.

There is no marked break to be detected anywhere between the gneiss and the overlying limestone. Apparently the whole is a continuous series of strata, which are analogous in appearance with those of the Grenville series of Canada. It therefore does not appear certain that in the eastern Adirondack region there are any rocks older than this series. The extent and persistence of the limestones and schists give ground for believing that the series was a set of calcareous sediments and sandstones which have been metamorphosed and intruded by the anorthosites.

Darton,[35] in 1895, describes and maps the faulted region of Herkimer, Fulton, Montgomery, and Saratoga counties, N. Y. Laurentian rocks occupy the northern part of the area, forming the floor for a succession of sandstones, limestones, and shales, which dip to the south at a very moderate angle.

Cushing,[36] in 1896, argues for the existence of pre-Cambrian as well as post-Ordovician dikes in the Adirondacks and along Lake Champlain, offering the following reasons: (1) A much larger number of dikes occur in the pre-Cambrian than in the Paleozoic rocks. (2) A great proportion of the dikes are of diabase, while diabase rocks are not found outside of the pre-Cambrian areas. (3) Along the line of contact of the Potsdam with the older rocks north of the Adirondacks the plentiful diabase dikes in the older rocks are apparently cut off by the Potsdam.

Kemp,[37] in 1897, describes the geology of the magnetites near Port Henry, N. Y., and especially those of Mineville, in the Adirondacks of New York. The oldest rocks present in the district are quartzose gneisses and white crystalline limestones, with perhaps some more basic gneisses. The limestones appear to lie largely in the upper part of this group, but some of them are certainly below the other members. The acidic gneisses may have been granites or quartz diorites. The gneiss and limestone group is cut by anorthosite intrusives, and both are in turn cut by gabbro intrusives. Trap dikes, usually of small width, are very common in this district. The age of these dikes is undetermined, but it seems probable that they may be of two ages, pre-Potsdam and post-Utica. Overlying unconformably all of the above-described rocks is the Potsdam sandstone.

Kemp,[38] in 1898, continues his preliminary report on the geology of Essex County, N. Y., with an account of the detail geology of the individual townships. The additional observations have corroborated the conclusions reached in his previous report on this county,[a] concerning the main classification of the rocks of the area, although it is now doubtful if a sharp stratigraphic distinction can be drawn between series 1 and 2.

Cushing,[39] in 1898, describes the geology of Clinton County, N. Y. Following Kemp, he gives the pre-Cambrian succession as: (1) A basal gneissic series; (2) a series of schists and gneisses, with crystalline limestone; (3) igneous rocks of the gabbro type, intrusive in the first two series. All of these are overlain unconformably by Paleozoic sediments. This classification is tentative, and probably simpler than the one finally adopted is likely to be.

1. The bassic gneissic series appears in the western tier of townships of the county, with the exception of Clinton, Peru, and Ausable. The gneisses comprise several varieties, varying widely in texture and composition.

2. The series of schists and gneisses, with crystalline limestone, occurs only in Black Brook Township. The limestone is coarsely crystalline, and much of it is nearly pure, but very often it contains a large amount of green pyroxene.

3. The gabbros occur in three areas, which are outliers of the main gabbro massive of the Adirondacks. One is in Ausable Township, extending north and west of Keeseville, and is the direct prolongation northeastward of a great gabbro ridge which comes up to Keeseville from the southwest. The second forms Rands Hill, in Beekmantown and Altona townships, 20 miles north of the first one. The third area forms the Catamount Mountain ridge, in southwestern Black Brook Township.

After the intrusion of the gabbro and prior to the Potsdam deposition the region was subjected to intense metamorphism, resulting in the formation and granulation of the rocks, with or without subsequent crystallization.

Smyth,[40] in 1898, reports on the crystalline rocks of St. Lawrence County, and particularly the towns of De Peyster, De Kalb, Hermon, Edwards, Canton, Russell, Potsdam, Pierrepont, and Parishville, together with points reexamined in the towns of Gouverneur, Rossie, and Fowler, which were covered in the examination made during 1893. The crystalline limestones, for which, in a previous report, the name Oswegatchie series was suggested, form belts stretching in a northeast-southwest direction. Four belts comprise a large proportion of the crystalline limestones of the region examined. The largest, the Gouverneur belt, extends from Antwerp to probably 2 miles south of Canton village. Northwest of this belt another extends from

[a] See Thirteenth Ann. Rept. New York State Geologist, for 1893, published in Forty-seventh Ann. Rept. New York State Museum (for 1893), 1894, pp. 625–666. Summarized in Jour. Geology, vol. 6, 1898, pp. 528–529.

Theresa, across Rossie and Macomb, into De Peyster. This belt is perhaps separated from the first by narrow strips of gneiss, along the northern boundary of Gouverneur, although the precise extent of the gneiss belts is undetermined. The third, the Edwards belt, to the south of the Gouverneur belt, and separated from it by a belt of gneiss, begins in Fowler, crosses Edwards, and runs out in the western part of Russell. The fourth, the Diana belt, south of the Edwards belt, and separated from it by gneiss, crosses the towns of Pitcairn and Diana. In general, the limestones have their greatest development in the northwestern part of the region, decreasing as the eastern and southern parts of the district are approached.

The limestone is everywhere thoroughly crystalline, ranges in color from white to dark bluish-gray, and often contains disseminated and aggregated silicates, of which the more important are serpentine and tremolite.

The term gneiss is used to include rocks ranging from acidic to basic, from fine to coarse grained, and from distinctly gneissoid, or even schistose, to entirely massive. They constitute a complex series of rocks, differing somewhat in age, and largely, if not almost wholly, of igneous origin. Parts of this series are clearly younger than the limestones; other parts may be older than the latter formation, but there is nothing as yet to prove that such is the case. A probable exception to the last statement is afforded by certain laminated gneisses, of limited extent, which appear to underlie the limestone, perhaps marking the base of the series.

Many of the gneisses have heretofore been believed to be sedimentary, and the evidence leading to the conclusion that they are largely igneous may be briefly summarized: The negative evidence of the absence of all structures pointing to sedimentary origin; the uniformity of composition and structure over wide areas, with changes by gradual transition; a common occurrence of massive cores, in every way identical with plutonic rocks; the presence of structures in the gneiss that would result from the application of pressure to igneous rocks; eruptive contacts between the abundant light-colored gneiss and the less common and older dark gneiss, together with widespread instances of inclusions of the dark gneiss in the light; the identity of the gneiss near Natural Bridge with the plutonic gabbro intrusive in the limestone; eruptive contacts of the gneisses with the limestone at a number of places.

CUSHING,[41] in 1898, describes syenite porphyry dikes in the northern Adirondacks. They are shown to be of pre-Cambrian age, but later than the gabbros and granites of the region. The syenite porphyries constitute the complementary rocks to the diabases of the region, and together with them form an eruptive assemblage similar to that which characterized Keweenawan time in the Lake Superior region.

Kemp,[42] in 1899, in connection with the description of the magnetite deposits of the Adirondacks, briefly describes the general features of the geology of the gabbro and gneiss of Westport, Elizabethtown, and Newcomb townships in Essex County, N. Y., and presents a geological map of Westport and Elizabethtown townships.

Cushing,[43] in 1899, maps the boundary between the Potsdam and pre-Cambrian rocks north of the Adirondacks, from the line between Clinton and Franklin counties, westward across Franklin County into St. Lawrence County, to a few miles west of Potsdam.

The sequence of rocks in the region is believed to be as follows:

1. A series of gneisses of great variety of structure and composition, in which all original structures are lost, of igneous origin, and in part at least of Archean age. They seem to grade into the basic gabbros of the region; at least the gabbros present phases not to be distinguished from the gneisses.

2. The Grenville series (Oswegatchie series), comprising quartzose gneisses and schists, quartz-feldspar-biotite gneisses, dioritic and gabbroic gneisses, and occasional bands of coarsely crystalline limestone. These rocks are accompanied by belts of gneiss, similar to the older gneiss, which seem to be interstratified with the other rocks of this series, but whose relationships are doubtful. The gneiss of the Grenville series differs in appearance from the older gneiss, and a considerable portion seems to be unquestionably of sedimentary origin, although dynamic metamorphism has obscured all traces of clastic structure and has given the gneiss a foliation in common with the older gneisses, rendering the field relations obscure. From Parishville westward to Potsdam the Grenville series is more widely distributed, less faulted, and less completely metamorphosed (and hence its sedimentary character is less disguised) than the Grenville series farther east, probably because of its greater distance from the anorthosite intrusion. However, it seems to be beyond question that the eastern and western series are equivalent.

3. The anorthosite intrusion.

4. Later gabbros.

5. Granitic intrusions. The region was then subjected to intense dynamic metamorphism, after which occurred the intrusion of

6. Diabase and trachyte dikes.

7. Paleozoic rocks overlying unconformably all the preceding.

Smyth,[44] in 1899, summarizes his ideas to date on the geology of the Adirondacks. Gneisses, limestone, and gabbro are the principal rocks. From studies in the western Adirondacks it is certain that some of the gneisses are of igneous origin, being granites, syenites, gabbros, etc., which have been modified by metamorphism; while others, with equal certainty, are altered sediments. But by far the larger part of the gneisses have not yet received careful study. The limestones are certainly sedimentary. Their relations to the gneisses are in doubt, but some parts of the gneisses are certainly younger than the limestones, and this may be true of all. The gabbro breaks through both gneisses and limestones. It presents two phases—an anorthosite and a gabbro containing abundant pyroxene and other ferromagnesian minerals. In places also in the western Adirondacks the granites and syenites break through the limestone.

Cushing,[45] in 1899, describes an augite syenite gneiss near Loon Lake in the Adirondacks. It is nearly related to the anorthosites in age, inasmuch as it is intrusive in the Grenville series, but it is much older than the pre-Potsdam diabases of the region. A study of the relations of the syenites and anorthosites indicates that the syenites are in part a result of differentiation in the anorthosite magma after reaching its place of final cooling, and in part somewhat later in date.[a]

Kemp and Newland,[46] in 1899, make a preliminary report on the geology of Washington, Warren, and parts of Essex and Hamilton counties, N. Y. Some of the points particularly noted are:

The excessive mashing and granulation of the gneisses, giving them in places semblance to quartzite. The greenish gneisses, consisting in largest part of microperthite, were originally eruptive rocks. The discovery is reported of quartzose gneisses or foliated quartzites which are certainly metamorphosed sediments. They form notable areas along the head of South Bay, Whitehall Township. Their presence indicates the probable presence of a considerable series of clastic sediments. The crystalline limestones themselves have been found in small exposures over almost all of Warren County, and generally in the crystalline belt of Washington. They are most extensive in Newcomb and Minerva townships of Essex, and to the south become thinner and more scattered. So far as we have observed they are less common in eastern Hamilton County. There is evidence to show that stratigraphic relations can be proved and that anticlines and synclines can be demonstrated.

Dikes of basic gabbro, usually of moderate width, but lithologically like the larger masses in Essex County, have been met over a wide area—in fact, in almost every township in Warren, but the basaltic traps almost disappear.

Smyth,[47] in 1899, discusses certain features of recent work in the western Adirondack region. He concludes that the rock previously called gabbro by Nason, Van Hise, Williams, and himself, south of the belt of limestone in the Diana-Pitcairn area in Lewis and St.

[a] The anorthosites are a part of the great gabbro mass which forms the core of the Adirondacks intruding pre-Cambrian sedimentary and igneous gneisses.

Lawrence counties, is an augite syenite of igneous origin, although it passes into a hornblende gneiss which is unquestionably a result of dynamic action. The origin of other gneisses has been inferred to be igneous from their similarity to this gneiss, which has been particularly studied, and it is evidence of this kind which serves as a basis for Smyth's conclusions, previously published, that some of the gneisses on the western Adirondacks are certainly, and most of them probably, of igneous origin.

With the view of exploring the central and little known portion of the Adirondacks, a reconnaissance was made through the area contiguous to the Fulton chain of lakes and Raquette Lake, in the counties of Hamilton and Herkimer. It was found that the heart of the Adirondacks is made up essentially of gneiss, with minor quantities of crystalline limestone and its associated sedimentary gneisses and schists. This is precisely analogous to what was found by the writer in St. Lawrence, Jefferson, northern Lewis, and southwestern Hamilton counties, and by Kemp and Cushing in the eastern Adirondacks. These facts lead to the conclusion that the Adirondack region, instead of consisting of a great central mass of gabbro, surrounded by a narrow fringe of gneisses and limestones with quaquaversal dip, is essentially composed of gneisses, with numerous limestone belts, having northeast strike and northward dip, and cut through on the east by immense intrusions of gabbro. It is still possible, of course, that some areas of gabbro may be found in the unexplored portions of the western half, but even should this be so it would not materially modify the above conclusion, as such masses must necessarily be isolated intrusions of no great extent, rather than parts of a large area.

Kemp,[48] in 1900, summarizes the present knowledge of the pre-Cambrian rocks of the Adirondacks. Most of the features have been covered in previous articles. Attention is called to the distribution of the sedimentary crystalline rocks, the Oswegatchie series (equivalent to the Grenville series of Adams and perhaps the Huronian). These consist of limestones, sedimentary gneisses, and quartzites. They occupy a greater area than has been supposed. The limestones are found chiefly in the northwestern and southeastern or eastern portions of the Adirondack area of crystalline rocks. They are in small quantity or altogether absent in the northern portion, in the broad belt running from northeast to southwest across the area, and along the southern and southwestern border. On the northwest they are in extended and comparatively broad belts, but in the eastern portion they appear in many small and separated exposures, associated with some quartzites and much greater amounts of characteristic gneisses, but greatly broken up by igneous intrusions. The quartzites thus far known are in small quantity, and are found principally in the eastern portions of the area, where the limestones are thinnest and most scattered. From the presence of the quartzites it is inferred that clastic sediments must have been present in larger amounts than has heretofore been realized. On the east it has not been proved that sediments form synclines pinched into the underlying gneissoid rocks; on the contrary, they seem to constitute low-dipping, flat monoclines.

Kemp,[49] in 1900, describes and maps the geology of the Lake Placid region in the Adirondacks, in the northwestern part of Essex County. Crystalline rocks of Algonkian age occupy a large part of the area. These include crystalline limestone, quartzite, granite, gneiss, and anorthosite. It is probable that some of the gneisses, especially those associated with the limestones and quartzites, are altered sediments, and it is also probable that the gneisses with augen of labradorite are squeezed igneous rocks, but the investigation does not permit of their separation. The anorthosites have intruded and metamorphosed the limestones and quartzites, and probably some of the gneisses. It has been noted that the anorthosite frequently passes outward by gradual transition into the dark gneisses with labradorite augen. Cutting all the above rocks are trap dikes, but whether pre-Cambrian or later is unknown.

Smyth and Newland,[50] in 1900, report progress in the mapping of the crystalline rocks of the western Adirondack region. Inclusions of hornblende schist found in the more acidic gneisses of the region are believed to afford important evidence as to the origin of the gneisses. Also light-red granitoid gneiss has been found intrusive into a gray gneiss, indicating, as before held, that all the gneisses are not of the same age. Certain of the gneisses are found to be younger than and intrusive into certain schists associated with the limestones.

Kemp, Newland, and Hill,[51] in 1900, further discuss the geology of Hamilton, Warren, and Washington counties, extending the observations noted in previous reports to the west and south.[a] The additional points of interest are the occurrence of anorthosites in Johnsburg, in Warren County, the southernmost exposure yet known in the eastern mountains, and the increasing certainty of the existence of sedimentary gneisses in Fort Ann and Johnsburg townships.

Cushing,[52] in 1900, describes and maps the pre-Cambrian rocks of Franklin County, N. Y. These are classified as Grenville (Algonkian) rocks, igneous rocks intrusive in the Grenville, and other igneous rocks of doubtful age, possibly in part older than the Grenville rocks.

The Grenville rocks occur in small disconnected patches surrounded by intrusive igneous rocks. Some of them have such position with

[a] For general discussion of classification of geology of these counties see Seventeenth Ann. Rept. New York State Geologist, for 1897, published in Fifty-first Ann. Rept. New York State Museum, vol. 2, 1899, pp. 499–553.

reference to one another that they seem to represent remnants of what were originally two continuous parallel northeast-southwest belts. The characteristic rock of the series is the crystalline marble. This is intricately infolded with quartzose and hornblendic gneisses and with fine-grained granitic, syenitic, and gabbroic gneisses, precisely like gneisses which occur in other areas where no member of the Grenville series is to be found.

The gneisses of undetermined age include granite, syenite, diorite, and gabbro gneisses, together with intermediate varieties. They occupy a very large area. If all these gneisses are igneous (as is thought probable) there are three possibilities in regard to their age:

1. They may represent in whole or in part a more ancient series than the Grenville.

2. They may represent a somewhat later series intrusive in the Grenville, but older than the great gabbro, syenite, and granite intrusions.

3. They may represent thoroughly foliated phases of these later intrusions.

In Cushing's present judgment they will be found to belong partly under 2 and partly under 3, but more especially the former.

No rocks have been found in the northern Adirondacks which can be shown to be older than the Grenville series, but in every case in which the relations have been made out the adjacent rocks show intrusive contacts with the Grenville rocks. On the other hand, the Grenville is a sedimentary series and must have been laid down on some floor.

Younger than the Grenville rocks and for the most part younger than the doubtful gneisses are a considerable quantity of igneous rocks, comprising gabbros (anorthosites), syenites, and granites. These again occupy large areas.

In the northern portion of the county Upper Cambrian rocks overlie the pre-Cambrian rocks with unconformity.

Smyth,[53] in 1901, describes and maps the geology of the crystalline rocks in the vicinity of St. Lawrence River in the town of Alexandria and parts of Clayton and Theresa in Jefferson County, together with portions of Rossie and Hammond in St. Lawrence County. Within this area are included the Thousand Islands of St. Lawrence River. The four rock types are crystalline limestone with schists, gneiss, granite, and Potsdam sandstone. The term schists is here used to include a variety of rocks, such as quartzite, hornblende and mica schists, hornblende, pyroxene, and mica gneisses, etc. The crystalline limestones and associated schists have for the most part the aspect of sedimentary rocks and are so classed. The gneiss is a complex so far as age is concerned, although the differences in the ages of the members are slight and discrimination of the units is not now possible. The gneisses are the most widespread of the pre-Cambrian rocks. The schists and quartzites, as seen in place, are found to be cut and veined in every direction by a granite gneiss, and fragments of schist and quartzite in every way identical with the main mass are scattered through the granite gneiss and are themselves penetrated by networks of dikes running in from the latter. The granite is also intrusive into the sedimentary series, but its relations to the gneisses are doubtful, although it has a close genetic relationship with them as a whole.

Kemp and Hill,[54] in 1901, report progress of work on the pre-Cambrian formations in parts of Warren, Saratoga, Fulton, and Montgomery counties.

Cushing,[55] in 1901, maps and describes the geology of Rand Hill and vicinity, Clinton County. The basal rocks are gneisses of the Dannemora formation occurring in the southwestern portion of the area. These are of doubtful origin, but probably mostly igneous. Intrusive in them are undoubted igneous rocks—gabbro, anorthosite gabbro, augite syenite, syenite, and dikes of syenite and diabase.

Cushing,[56] in 1902, describes a pre-Cambrian outlier at Little Falls, in Herkimer County, N. Y., and points of difference from the syenite of the Adirondacks.

Cushing,[57] in 1902, discusses recent geological work in Franklin and St. Lawrence counties, N. Y., and concludes that:

1. The Adirondack anorthosite is cut intrusively by an augite syenite, which is therefore younger.

2. While the larger part of the augite syenite of the Adirondacks is in such situation with respect to the anorthosite as to render impossible any determinations of relative age, its general character is so uniform throughout that it is exceedingly probable that it is all of the same approximate age and consists of intrusions from the same source.

3. At their borders these syenites pass over into granites, part of which at least cut the syenite eruptively and are therefore younger.

4. The syenite grades into granite on the one hand and into gabbro diorite on the other, and apparently into anorthosite as well.

5. The three together—anorthosite, syenite, and granite—form a great eruptive complex in the heart of the Adirondack region, and all are younger than the (in part at least) sedimentary Grenville rocks.

Cushing,[58] in 1905, maps and describes the Little Falls quadrangle, bordering the Adirondacks and the Mohawk Valley. Pre-Cambrian rocks occupy the northeastern portion of the quadrangle, forming a part of the main Adirondack area, and are found also at three disconnected localities to the southwest—Little Falls, Middleville, and a spot 2½ miles northeast of Little Falls.

The main area on the northeast consists of syenite, usually gneissoid, of post-Grenville age. Associated with this are smaller areas of Grenville rocks. These comprise a series of light-colored, often white, gneisses, very rich in quartz, interbanded with less quartzose rocks of darker color, and often with a very respectable percentage of black minerals—hornblende, black mica, and magnetite. The argument for their sedimentary origin rests on their composition, mineralogical and chemical, and on their frequent variations in composition, beds of different original character having produced differing metamorphic rocks, whose comparatively sharp junctions look like old bedding planes. At most of the Grenville exposures of any extent rocks which are regarded as igneous are found mingled with them. They are always thoroughly gneissoid and are interbanded with the old sediments. They are thought to represent old dikes and sheets of igneous rock, possibly surface flows also, which were formed during or not long after the deposition of the sediments.

At Little Falls and Middleville the rocks are mainly syenite, mostly augite syenite, sometimes porphyritic, usually gneissoid, of post-Grenville age, but much older than the diabase. At the outlier northeast of Little Falls is gray gneiss which is provisionally classed with the green gneiss associated with the Grenville rocks.

Cushing,[59] in 1905, summarizes the geology of the northern Adirondack region, and concludes that while in many parts of the Adirondacks areas of varying size are found in which the rocks that occur may be unhesitatingly classed as Grenville sediments or as later igneous intrusions, over much of the district this is not the case, but an intimate admixture of various rocks is found, in apparently hopeless confusion. Thus we find Grenville sediments elaborately interbanded with other rocks, apparently igneous, yet seemingly conformable with them as an integral part of the series. We also find rocks which are not to be distinguished in appearance or in composition from the rocks of the great intrusions, except for perhaps a more thoroughly gneissoid character, and yet so interwoven with other rocks, so far as yet known not represented in the great intrusions, that it hardly seems possible that the two can belong together. There are also considerable areas of gneisses which are quite like the uncertain gneisses involved often with the Grenville rocks, yet without any Grenville admixture, and the relationship of such rocks forms a very difficult problem. The Grenville belts and patches and the areas occupied by the later igneous intrusions have been in the main discovered and mapped. There yet remains the exceedingly difficult problem of the separation of these mixed belts into their several elements and the working out of their affiliations. This is likely in many cases to prove impossible, and in nearly all cases the amount of intermingling is so great as to render attempts at detailed mapping of the several elements futile, and to require their designation as belts of mixed rocks. The great metamorphism which has destroyed the old rock structures and given them a common foliation, the inextricable intermingling of igneous rocks with the Grenville sediments, and the later great igneous invasions from beneath have so disguised the rock relationships as to make it very likely that the base of the Grenville will never be satisfactorily made out in the region.

CUSHING,[60] in 1907, maps and describes the geology of the Long Lake quadrangle, in the heart of the Adirondacks. With the exception of the recent unconsolidated surface deposits all the rocks are of pre-Cambrian age, and they may be grouped as follows:

1. A series of old sedimentary rocks, the Grenville series, much involved with igneous rocks, some of which seem of approximately the same age.

2. A series of gneisses which seem to be mainly or wholly of igneous origin; they may be in part older than the Grenville rocks, though no certain evidence of this has yet been forthcoming in the Adirondack region. If there are in the region any exposed rocks more ancient than the Grenville rocks, they are these.

3. A series of igneous rocks, usually in great masses (batholiths), which are demonstrably younger than both the preceding, and which are not so profoundly changed in character, in many places retaining traces of their original textures and structures.

4. A series of very much younger igneous rocks which have undergone little change since their intrusion.

All but the last have an extensive representation, the quadrangle being rather unusual in this respect.

The Grenville series consists of well-banded gneisses and schists, some of them grading into quartzites, with bands of coarsely crystalline limestone of varying thickness. There is apparently a great thickness of these rocks, but neither their base nor their summit is known, and they are so disturbed and usually so poorly exposed that our ideas concerning their thickness are extremely vague. They must have been deposited upon a floor of older rocks, but we are at present ignorant as to what these rocks were, and whether or not they are anywhere exposed in the district.

ADAMS, BARLOW, COLEMAN, CUSHING, KEMP, and VAN HISE,[61] forming a special committee on the correlation of the pre-Cambrian rocks of the Adirondack Mountains, the "Original Laurentian area" of Canada, and eastern Ontario, in 1907, consider the pre-Cambrian sedimentary development in the area examined by them as represented by one great series. This series is essentially identical in petrographical character throughout the whole region.

The only locality where the possible (Coleman would say probable) existence of a second unconformable sedimentary series was suggested by the facts observed was on the Queensboro road east of Madoc, Ontario. It is, however, still uncertain whether or no the conglomerate here developed marks the base of an overlying, infolded, unconformable series.

In Logan's original classification of the Laurentian this term—apart from the Upper Laurentian, which was proved to be composed essentially of anorthosite intrusions—included two series differing in character, namely, the lower orthoclase (Fundamental) gneiss and the Grenville series. Now that investigations have shown that these two series differ in origin, one being essentially a great development of very ancient sediments, and the other consisting of great bodies of igneous rock intruded through them, it becomes necessary to separate these two developments in drawing up a scheme of classification.

As the great intrusions of gneissic granite, forming what has been termed the "Fundamental gneiss," have an enormously greater areal development than the overlying sedimentary series, constituting, as they do, a very large part of the whole northern protaxis, the committee recommends that the term "Laurentian" be restricted to this great development of igneous gneisses. The nomenclature suggested for the pre-Cambrian rocks of this eastern region will thus conform, so far as the use of this term is involved, with that suggested by the special committee for the Lake Superior region.[a]

For the overlying sedimentary series the committee recommends the adoption of the name "Grenville series," as it is the name originally given by Logan to the series as typically developed about the township of Grenville, in the "Original Laurentian area," on the north shore of the Ottawa River, in the Province of Quebec, between the cities of Montreal and Ottawa. The term "Hastings series," in the opinion of the committee, should be abandoned as a serial name, seeing that the development to which this name was applied by Logan is merely the Grenville series in a less altered form, as Logan in giving the name had conjectured was probably the case. The committee, however, thinks that it may in some cases be advantageously employed as a qualifying term to designate the less highly altered phase of the Grenville series, which may thus be referred to as the "Hastings phase" of the Grenville series.

In Canada this Grenville series everywhere, on going north, is invaded by and frays away into the great Laurentian batholiths, while in the Adirondacks it is cut to pieces by the great intrusions of that area, which, when worked out in detail, may prove also to have a more or less similar batholithic form.

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[a] See Jour. Geology, February–March, 1905.

The following succession in this region is therefore recognized and adopted by the committee:

Cambrian: Potsdam sandstone, etc.
 Unconformity.
Pre-Cambrian: Grenville series.
 Intrusive contact.
Laurentian.

The committee considers that it is inadvisable in the present state of our knowledge to attempt any correlation of the Grenville series with the Huronian or Keewatin, so extensively developed in the region of the Great Lakes. The Grenville series has not as yet been found in contact with either of these, and until this has been done and the relations of the several series have been carefully studied their relative stratigraphic position must remain a mere matter of conjecture.

NEWLAND and KEMP, [61a] in 1908, discuss the geology of the Adirondack magnetic iron ores. Their paper includes a good general account of the geology of the Adirondacks and a detailed discussion of the geology about certain magnetite deposits, but the essential features for purposes of this bulletin are covered in preceding summaries.

SUMMARY OF PRESENT KNOWLEDGE.

The Adirondack region constitutes a great pre-Cambrian outlier surrounded by Paleozoic sediments. It may be said at the outset that the rocks and their relations are very similar to those of the original Laurentian area. In the region there are two great classes of rocks—metamorphosed sediments and igneous rocks.

The sediments consist of three classes of rocks—gneisses, limestones, and quartzites. The gneisses, which are almost certainly of sedimentary origin, are usually graphitic, garnetiferous, micaceous, pyroxenic, hornblendic, or some combination of these. Moreover, the sedimentary gneisses are closely associated and interstratified with the limestones and quartzites. Within the sedimentary series are workable beds of magnetic iron ore. The limestones are pretty well scattered throughout the Adirondack district. In the eastern and central portions of the district they usually appear in rather small and separated exposures. In the northwestern part of the district they are much more prevalent. Here the largest belt is 20 miles long and 6 miles broad. The quartzite and quartz schists are less abundant than either the sedimentary gneisses or the limestones. They are apparently more prevalent in the eastern than in the western portion of the district.

The igneous rocks have the greatest variety. The most abundant is gneiss, which includes granite gneiss, syenite gneiss, diorite gneiss, gabbro gneiss, etc., with intermediate varieties. The most abundant massive rocks is gabbro, which varies into anorthosite on one side and syenite on the other. In the eastern part of the district especially the gabbro occurs in great batholithic intrusions. Later diabases are subordinate igneous rocks.

Much attention has been given to the study of the nature and relations of the various gneisses of the district. Some of the gneisses are sedimentary and some of them are igneous, but the origin of the great body of them is in doubt. Statements of the relative abundance of these classes of gneisses vary for different writers, for different parts of the district, and for different stages in the progress of the mapping. But there has been recently a marked tendency toward increasing emphasis on the abundance of igneous gneisses, although the presence of sedimentary gneisses interbedded with the limestones is conceded by all.

Recent workers have concluded that the igneous gneisses are mainly intrusive in the sediments. Thus Cushing states, for the northern part of the district, that while the relations of most of the gneisses are unknown, wherever units have been separated from the gneissic complex they have been found to be intrusive into the sedimentary series; that most of the gneisses will be found to be intrusive into the sediments; and that no rocks have been found in the northern Adirondacks which can be shown to be older than the sedimentary series. Smyth, who worked on the western and northwestern side of the Adirondacks, concludes that some gneisses are certainly, and most of them probably, of igneous origin and intrusive into the limestones. He also thinks that near Natural Bridge certain of the hornblende gneisses result from the deformation and alteration of the augite syenite. Kemp, principally from his studies on the eastern and southeastern sides of the district, concludes that the gneisses, where separated, are intrusive into the sedimentary series and that there is no certain evidence of the existence of basal gneisses in the area studied by him.

In general, then, the origin and relations of a large body of the igneous gneiss are unknown. Where the relations are clear it is found that gneisses are intrusive into the sedimentary series, and as yet no decisive evidence of the existence of basal gneisses has been presented, although the possibility of its presence is not denied by any of the men who have studied the region.

Some of the gneissic beds are interlaminated with the limestone; these are garnetiferous and micaceous, or pyroxenic and hornblendic. Near Hague is a bed of strongly graphitic gneiss between beds of ordinary gneiss, which, viewed at a distance, has the appearance of a layer of coal in an ordinary bedded succession. The gneisses interlaminated with the limestone are everywhere completely crystalline. Neither macroscopically nor microscopically do any of them show clastic structure. but the original beds were not obliterated. The direction of the bedding may therefore be determined in parts of the region by the contacts of the layers of different lithological characters. So far as observed, the schistosity of the series corresponds with the bedding.

Between the marble-bearing gneisses are gneisses free from limestone, which are red or gray and orthoclastic. The broader of these areas are on the southern and western sides of the Adirondacks.

At many places the contact of the marble with the gneiss is of an extraordinary character. The plane between them is one of great irregularity. Interstratified with the limestone are gneissic or pegmatitic layers. As a result of a strong movement, at many localities the interstratified gneiss and pegmatite have been broken into fragments which are contained within the marble, thus producing autoclastic rocks which in some places simulate remarkably erosion conglomerates. Between the breccia and the interlaminated gneiss, pegmatite, and marble there are all gradations. The marble associated with or containing the disrupted fragments of the gneiss in some places shows no evidence whatever of movement, being massive and coarsely crystalline. The included fragments and gneiss adjacent, on the other hand, give all the evidences of deformation.

The gabbros and their associated phases, anorthosite, syenite, and granite, are all intrusive into the entire sedimentary series. The diabase dikes are the latest intrusives of the district.

Correlation.—The sedimentary gneisses, limestones, and quartzites have been called the "Oswegatchie series" by Smyth. Following the conclusions of the international committee in 1906, there is little doubt that this series may be safely correlated with the Grenville series of the original Laurentian and Hastings districts. This being the case, the term Grenville has priority and the name "Oswegatchie" is unnecessary. When it is determined where the Grenville series of the Laurentian district belongs with reference to the Archean or the Algonkian, this will solve in large measure the problem of correlation of the Adirondack Grenville. It is regarded as probable by Adams that the "Grenville" limestone represents mere shreds of what was once a continuous sedimentary formation that covered the region and was continuous with the less metamorphosed Hastings series.

Miller and Knight, on the other hand, find the Grenville series to be unconformably below at least part of the Hastings, also containing limestone, and above basic igneous flows. They conclude that the "Grenville" limestone shows the same relations to the basic igneous rocks as do the Keewatin iron-bearing formations to the Keewatin greenstones of the Lake Superior region, suggesting correlation of the Grenville with the Keewatin.

The mapping of the Adirondack region has not yet discriminated a later sedimentary series, and the whole is therefore mapped as unclassified pre-Cambrian.

SECTION 2. SOUTHEASTERN NEW YORK.

SUMMARY OF LITERATURE.

PIERCE,[62] in 1818, describes the nucleus of Staten Island as consisting of steatite, which stamps the formation as Primitive.

AKERLY,[63] in 1820, describes a section running from Long Branch, in New Jersey, northward to New Marlboro, Ulster County, N. Y. The rocks included are divided into principal rocks, metalliferous rocks, basaltic rocks, and alluvial formations, which correspond to the German terms Primitive, Transition, Floetz, and Alluvial. Staten Island has a rocky base composed of the magnesian order of rocks, consisting of serpentine and steatites or soapstones. Hoboken is of the same nature as Staten Island. The Highlands of New York consist of granitic rocks belonging to the Primitive class. Gneiss and micaceous schist are the most prominent; but granite, properly speaking, also enters into the composition. The commencement or termination of any of these rocks has not been found, and as they graduate into one another they are considered the same formation. At Hell Gate the rocks are gneiss and micaceous schist. The northern part of New York Island is of the Primitive formation and includes granite, gneiss, and limestone. Crystalline limestone is also found at other points. All these rocks are placed in the Primitive formation, and they contain no organic remains.

EATON,[64] in 1822, describes as occurring in the Highlands of the Hudson, without reference to order of time, gneiss, hornblende rocks. and argillite. The gneiss appears to be the center or oldest formation.

MATHER,[65] in 1838, mentions gneiss on Long Island; granite and serpentine on Staten Island; and granite, gneiss, and granular quartz in the southeastern part of Dutchess County. In the serpentine was observed a trap rock.

MATHER,[66] in 1839, describes the rocks of New York, Westchester, and Putnam counties as comprising granite, gneiss, mica slate, quartz rock, talcose slate, limestone, syenite, serpentine, steatite, augite rock, and greenstone, the latter traversing the other rocks like veins or being interstratified with them. The gneiss and granitoid rocks are distinctly stratified, as is also the limestone.

HORTON,[67] in 1839, describes the Primitive rocks of Orange County as less regular in stratification and dip along the banks of the Hudson and at their western margin than in their center. The strike of the Primitive gneiss is about northeast-southwest, with a dip to the southeast from 45° to nearly vertical. Interstratified among the Primitive rocks are hornblende rock and white limestone. Argillite is placed with the Transition formations.

GALE,[68] in 1839, finds that the rocks of New York County are chiefly a gneiss, associated with which as subordinate rocks are serpentine, hornblende, Primary limestone, and anthophyllite rock. On the western side of the island the gneiss so abounds with veins of granite parallel with the strata that in many places they constitute the chief material. At Kings Bridge the limestone at its junction with the gneiss shows the structure of that rock with the mineral matter of limestone, but the pure limestone is in beds without stratification.

MATHER,[69] in 1843, gives a systematic account of the geology of the first district, comprising the southern part of the State. The Potsdam sandstone is at the base of the unmodified series. In places it is metamorphic and has more or less of the aspect of gneiss; at other times it is in an intermediate state, showing rounded gravel and sand. The dips are usually eastward at from 5° to 20°, but in the Hudson Valley it is upturned with other rocks at a high angle toward the east. The Taconic system consists of slates, limestones, and granular quartz rocks, which form a belt of mountainous country from Vermont to Peekskill on the Hudson and a narrow belt across the Highlands to the mouth of Peekskill Creek. They are again found on the right bank of the Hudson, between Stony Point and Caldwell's landing, and range south-southwest until they disappear beneath the red sandstone formation. The rocks of this system have the same strike and dip as those of the Champlain division, and apparently underlie them. The dip is in a general easterly course, varying from 15° to 90°. As to the superposition of the formations, the granular quartz either rests upon or pitches under the gneiss or granitic rocks. The limestones lie next in order from the gneiss or granite, either in super or sub position, and the slates next follow. This may be found difficult of verification, as the rocks are almost universally much deranged from their original position. Many local details are described, and it is concluded that the Taconic system represents the Champlain division metamorphosed. In favor of this conclusion are the facts that the succession is the same; that both of these systems are superimposed upon the Primary without any intervening strata; that the unmodified beds are traced into those that are metamorphic; and that the places where the rocks are most metamorphosed are those where there are intrusives and have been unheavals.

Under the head metamorphic rocks are described rocks which are not included in the foregoing and which, while there is no demonstrative evidence of it, are regarded as originally sedimentary rocks that have been so altered as to change them into such rocks as have usually been called Primary. The metamorphic rocks are divided into those east of the Highlands of the Hudson, and those of the Highlands of Saratoga and Washington counties. In the first district the limestones are granular, dolomitized, and stratified. The slates are talco-argillaceous, talcose, chloritic, or micaceous, the last predominating; and the sandstones are changed into granular quartz rock, eurite, and gneiss. In the second district the limestones are changed to white or red, coarse-grained, crystalline limestone, containing various crystallized minerals, with scales of plumbago, and rarely show any traces of stratification. The slate is changed to mica slate, micaceous gneiss, or hornblende slate, and the quartz rock is changed so as to be scarcely recognized as such. In the first class, also, the intrusive rocks bear but a small ratio to the altered rocks, and are mostly quartz and granite; but in the second class the undoubted plutonic rocks abound, and consist of granite, syenite, greenstone, augite, serpentine, diallage, and intrusive metalliferous veins.

The metamorphic rocks east of the Hudson and the Highlands are in a continuous range from Bennington in Vermont to the western part of Massachusetts and Connecticut and the eastern part of New York. Between the Taconic rocks and the metamorphic rocks to the east no well-marked line of distinction can be drawn, as they blend into each other by insensible shades of difference. In considering the metamorphic rocks as a whole the descriptions necessarily include certain of the Taconic rocks. The strata of metamorphic rocks are very much broken, so that no stratum has been traced continuously more than a few miles. The only beds which can be traced with any degree of success are the limestones, which are described in detail. The limestones of Westchester County have the same dip and line of bearing as the contiguous gneiss, and, like that, are distinctly stratified. They form several nearly parallel ranges at intervals of 2, 3, or 4 miles. They all dip east-southeast, with local exceptions, at a high angle, varying from 45° to 90°. The metamorphic slates of Dutchess, Putnam, Westchester, and New York counties have been traced in different localities through different modifications and texture from the gray and semicrystalline limestones associated with talcose slate and the sandstone of the Taconic system to the perfect dolomites and white and gray crystalline marbles associated with mica slate and granular quartz rock north of the Highlands, and to still more crystalline limestones associated with mica slate, micaceous gneiss, hornblende slate, hornblendic gneiss, hornblende rock, syenite, and granite south of the Highlands. In these latter limestones are frequently found some mineral substances, such as serpentine, brown tourmaline, copper and iron pyrites, magnetic sulphuret of iron, mica, and magnesian minerals, particularly where near to undoubted plutonic rocks. It is believed that all the crystalline limestones of Vermont, Massachusetts, Connecticut, and the eastern part of New York are metamorphic rocks; that they were originally the Mohawk limestone and Calciferous limestone, and that the associated rocks were originally the Potsdam sandstone and the slate rocks of the Hudson Valley; that they were, in fact, the rocks of the Champlain division, but much more altered and modified by metamorphic agency than the Taconic rocks.

In the study of the metamorphic rocks of the Highlands and Saratoga County, as in the other districts, most attention is given to the limestones. At Warwick the white limestone is rarely stratified or shows any distinct traces of stratification, but in some places it exhibits a regular gradation into the gray and blue limestone, which is fossiliferous in some places and oolitic in others, and stratified in nearly horizontal strata. The limestones of the Highlands of Orange, Rockland, and Putnam counties are in long, narrow belts associated with the granite, syenite, hornblende, and augite rocks and some anomalous aggregates. The limestones of Washington County are coarse, white, and crystalline. They contain various embedded crystalline and amorphous minerals, the most common of which are plumbago, augite, and hornblende. Hornblende, coccolite, and plumbago are the most constant associates. Scapolite is not uncommon. In some places the limestone is so much intermixed with other materials found in the gneissoid and granitic rocks that without close examination one would not suspect it of being a limestone. Quartz is frequently found in it, transparent or translucent, with irregular, rounded forms, as if it had been partially melted. Many localities visited show that it has been softened, if not melted. The similarity of the crystalline limestones of the northern counties to the crystalline phases of those at Warwick which grade unmistakably into fossiliferous forms leads to the conclusion that they are all really the same rock. The limonitic and hematitic ores are confined to the valleys of the Taconic and metamorphic rocks and are usually associated with talcky slate on one side and limestone on the other.

Under Primary rocks are included those usually called by that name and those not yet described as Taconic or metamorphic, though some of them are probably of the same age as the metamorphic rocks. This is particularly the case with the plutonic rocks, as granites, syenites, hornblende rocks, some of the trappean rocks, and the metalliferous beds and veins which have intruded themselves among and altered the adjacent rocks. The hornblendic gneiss, micaceous gneiss, and mica slate may perhaps be referred to the same period. The Primary rocks in the different districts are very similar. They include granite, syenite, gneiss, mica slate, augite rock, greenstone, hornblende rocks, quartz rock, talcose slate, limestone, serpentine, and steatite, although the last five have been already included among the metamorphic rocks. In Rockland and Orange counties the strata dip to the southeast at angles of 50° to 90°, but there are localities where the strike and dip are transverse to the general directions. Granite veins are very numerous in the granitic gneiss; the greenstones include basaltic greenstone or trap, granular greenstone, and Primitive greenstone. Associated with the Primary rocks is magnetic oxide of iron, confined to the southern counties of the Highlands and forming masses in gneiss and hornblendic gneiss rocks which might be called beds, but which are thought to be veins. Their course is parallel to the layers of rock, but in several instances after continuing with this parallelism for a certain distance the ore crosses a stratum of rocks and then resumes its parallelism, and then obliquely crosses another, and so on. Also in other places where there are great beds of ore a few small strips of ore penetrate the surrounding rocks as if they have been cracked asunder and these seams forced up from the main mass below.

The rocks that are most metamorphosed are usually near granite, syenite, trap, quartzose and metalliferous protrusions, dikes, and veins. It is believed that trappean injections took place as late as the time of the Red Sandstone of New Jersey. The granitic, syenitic, and augitic rocks appear to belong to the epoch immediately preceding the slates and grits of the Champlain division, since they have altered the preexisting rocks where they come in contact up to that time, but no traces of such changes are found in the more recent rocks. Another intrusion of granite is believed to have preceded the Red Sandstone of Rockland and New Jersey, being probably more recent than the rocks of the Catskill division.

Cozzens, jr.,[70] in 1843, divides the rocks of Long Island into granite, syenite, serpentine, mica gneiss, hornblende slate, quartz rock, Primitive limestone, and diluvium. The distribution of all is given. At the Palisades, on the west side of Hudson River, the section from the base up is granite, serpentine (different from that at Long Island), sandstone, greenstone slate, and trap. The section of Staten Island from the base upward is granite, serpentine, sandstone, trap or greenstone, beds of iron ore, and diluvium. At Donderberg the section is granite, gneiss, talcose slate, limestone (called Transition limestone), and brick clay.

Emmons (E.),[71] in 1846, gives a systematic treatment of the character and relations of the Taconic system. The Taconic system is held to be below the New York system, because the base of the latter is perfectly schistose, like that of the former, and because the material of the New York system is derived from the Taconic. Again, contacts between the Taconic system and the Calciferous sandstone and Hudson River shales show that the former are unconformably below the rocks of the New York system. An evidence that the Taconic system is newer than the Primary rocks is the occurrence of porphyritic quartz of the Taconic upon gneiss. It is, then, not to be doubted that there is a system of rocks lying between the Hoosac Mountain range and Hudson River of an age posterior to the gneiss and mica slate and anterior to the New York system. It consists throughout of beds of sedimentary matter in a state of fine division conformable to one another and arranged in uninterrupted succession, although their lithological characters are very diverse. The Taconic system comprises the Taconic slate, bearing fossils, the Sparry limestone, the Stockbridge limestone, and the brown sandstone or granular quartz. The Primary limestone carries graphite, and on this account can always be distinguished from Stockbridge limestone; also other minerals, such as spinel, sapphire, idocrase, hornblende, pyroxene, chondrodite, and mica, are found plentifully in the Primary, but do not occur in the Stockbridge. The rocks of the Taconic system are inverted and greatly disturbed, and their relations with the underlying and overlying rocks are obscure, so that the true structure can be ascertained only by the most careful examination.

CREDNER,[72] in 1865, states that the island of New York and the eastern part of Long Island consist of gneiss, which, toward the north, contains hornblende gneiss, hornblende schist, syenite, and hypersthenite, and in the last two are magnetite. The northern, hilly part of Staten Island consists of dioritic rocks and serpentine with layers of soapstone.

STEVENS,[73] in 1867, describes New York Island as consisting in the main of gneiss, in which lie veins and beds of granite, anthophyllite, and hornblende. The granite occurs in veins generally coincident with the gneiss, but also in massive beds which lie across the strata. In places it is distinctly separated, but in other places it insensibly blends into the gneiss. The hornblende and anthophyllite occur like the granite. Limestone occurs at several points and is interlaminated and folded with the gneiss. This New York group of rocks is like and regarded as equivalent to Emmons's Taconic. For it is proposed the name Manhattan group.

DANA,[74] in 1872, describes the mica schist of Poughquag as underlying conformably the Stockbridge limestone. The mica schist is underlain conformably by the gneiss of the Taconic series. Besides the limestones and Taconic schists and gneiss, there is near Poughquag, in still more intimate connection with the quartzite rocks of Azoic age, a continuation of the Highlands of New Jersey, which are probably Laurentian. But as this point is not definitely settled, and since the term Azoic has been ruled out by facts proving that the era was not throughout destitute of life, it is proposed to use for the Azoic area and its rocks the general term Archæan (or Archean). These Archean rocks, coarsely crystalline gneisses, are exposed in a deep cut on the Hartford and Fishkill Railroad. The quartzite formation of this region shows no conformity to the Archean gneiss, and none to the gneiss, mica schist, or limestone of the Taconic series. The nearly horizontal beds of quartzite lie on the nearly vertical Archean, and both occur within a few hundred yards of the steeply inclined Taconic beds.

Dana,[75] in 1880 and 1881, considers the geological relations of the limestone belts of Westchester County. The rocks here found are divided into metamorphic rocks, not calcareous; calcareous rocks or limestones; serpentines and other hydrous minerals; augitic and hornblendic rocks not above included. Of metamorphic rocks the prevalent kinds are micaceous gneiss, mica schist, ordinary gneiss, and granitoid gneiss. The calcareous rocks are white and coarsely crystalline, although locally they are feebly crystalline. The hornblendic and augitic rocks constituting the Cortlandt series include soda granite, norite, augite norite, diorite, hornblendite, pyroxenite, and chrysolitic kinds. These rocks are held to be conformable with a part of the adjoining schists and limestone, which are of metamorphic origin, although they may have been in a former state of fusion or plasticity. The limestones and adjoining schists are found to be one in series and system of disturbance, are considered a part of the Green Mountain system, younger than the Highland Archean, and probably Lower Silurian. At Annsville there is evidence of unconformity between the Archean and this series. The limestone here lies unconformably against the hornblendic contorted Archean gneiss. A similar unconformity exists half a mile northeast, although the upturning of the limestone and its associated schist has usually placed them in near conformity to the strike of the Archean rocks.

Dana,[76] in 1882, ascertained that a large part of the rocks referred to the Taconic Range are shown by their fossiliferous contents to be Silurian and the equivalent of the Hudson River group, although it is not asserted that all of the hydromica schists belong here. A part are Primordial.

Newberry,[77] in 1882, states that the mottled serpentine of New York Island is like the Moriah marble of the Adirondack region, which affords strong indication of a Laurentian age of the New York Island and Staten Island rocks.

Dana,[78] in 1884, finds that the hornblendic and augitic rocks of the Cortlandt series have such relations to the schists as to show that they are of igneous origin, the eruptions taking place subsequent to the era of the limestone, mica schist, and soda granite.

Smock,[79] in 1886, describes the crystalline rocks of Dutchess, Putnam, and Westchester counties. This district is divided into four belts: Stissing Mountain, East or Dover Mountain, Highlands of the Hudson, and Westchester County. The prevailing rocks of Stissing Mountain are gneisses, granites, granulite, and syenite, which resemble closely those of the Highlands of the Hudson. The rocks of the East Mountain comprise chiefly gneiss, granite, granulite, quartz syenite, syenite gneiss, and mica schist. Between the quartzite and the gneiss, when they are seen close to each other, is a lack of conformity. The more common of the rocks of the Highlands of the

Hudson are gneiss, syenite gneiss, granite, quartz syenite, granulite, and hornblende schist. The Poughquag-Fishkill quartzite is found to rest unconformably upon the Highland gneisses, the discordance being best seen on the New York and New England Railroad, 1 mile west of West Pawling station. Here the quartzite has a dip of 15° or 20°, while the gneiss, but 300 feet distant, has an almost vertical inclination. Belonging with the Archean gneisses are limestones, among which is that at Sprout Brook. On the eastern side of the Highlands the Archean border has the micaceous schistose rocks and the quartzites resting upon it. These relations are particularly well shown at Towner's station. Near here the limestones and schists in a syncline rest unconformably upon the granulitic gneiss. Provisionally the rocks of the Highlands are referred to the Archean. They may be all Laurentian also, but the Huronian has not been identified. In Westchester County is a great variety of crystalline rocks. To these is applied the name Manhattan gneiss, proposed by Hall. These rocks are less massive than those of the Highlands, include micaceous gneiss and schist, as well as crystalline limestones, and to the ordinary observer are more like the common fragmental rocks than the massive gray granitoid gneisses.

Hall (James),[80] in 1886, in describing the building stones, includes in the Laurentian rocks the granitic, syenitic, and gneissoid rocks, as well as the crystalline marbles which are everywhere interstratified with the gneiss rocks, but usually form a small proportion of the entire mass.

Williams,[81] in 1886, 1887, and 1888, describes the peridotites, norites, gabbros, and diorites of the Cortlandt series and their relations to the mica schists and limestones. They are regarded as eruptive rocks because they have the structure and mineralogical composition of eruptive types; because their schistose phases have nothing which suggests an original sedimentary structure, because they occur in well-defined dikes in other massive rocks, in mica schists, and in limestones; because fragments of crystalline schist and limestone are found inclosed within the massive rocks, and because contact phenomena are found in the crystalline schists and limestones adjoining them.

Britton,[82] in 1887, describes the serpentine of Staten Island as a stratified rock probably derived by the extensive alteration of limestones. This serpentine appears to overlie the crystalline limestones. These metamorphic rocks with the gneisses are regarded as Archean.

Kemp,[83] in 1887, describes Manhattan Island as consisting of a long ridge of gneiss, with Triassic trap and sandstone on the west and connected with the gneiss of the mainland on the north and south.

Merrill, [84] in 1890, agrees with Britton that the basal member of the pre-Cambrian of southeastern New York and New Jersey is a granitoid hornblende gneiss, which is followed by a second member, the iron-bearing group, and this in turn by the schistose group. The thickness of the pre-Cambrian rocks in the Hudson River Valley is between 2,300 and 2,800 feet. They are unconformably below the Cambrian quartzite, and nothing more definite can be predicted as to their age. These rocks display a number of anticlines, two of which are those at Fishkill and the Storm King. In the synclinal trough between are the rocks of the iron-bearing group. The metamorphic strata of New York and Westchester counties, called the Manhattan group, are classified in several divisions as follows, from the base upward: (1) Yonkers gneiss, which is an arkose gneiss; (2) Fordham gneiss, a quartzite gneiss; (3) Inwood limestone, and (4) Manhattan mica schists. The age of the Manhattan group has not been determined, but it is thought to be pre-Cambrian. This group and the Lower Cambrian sandstone are both found to lie on the second or iron-bearing member of the pre-Cambrian formation, and no unconformity has been found between the Manhattan group and the underlying pre-Cambrian beds. Of equal significance is the lack of unconformity between the Lower Silurian strata of Peekskill Hollow, Tompkins Cove, and Verplanks Point and the partially metamorphic beds of the Manhattan group.

Kemp and Hollick,[85] in 1894, find the granite at Mounts Adam and Eve, New York, to be intrusive within the limestone. Adjacent to the granites the limestone is white and crystalline and is charged with peculiar contact minerals. This white limestone grades into blue limestone with transitional graphitic forms. This limestone in New Jersey contains Cambrian fossils.

Kemp,[86] in 1895, describes the East River and Blackwells Island section made by an underground tunnel at Seventieth street, New York City. Under the west channel is a fine-grained mica gneiss containing pegmatite seams. Under Blackwells Island and the adjacent waters is a gray gneiss. In the center of the east channel is a dolomite, which is flanked on the east side by mica schist locally pegmatized. Beyond the mica schist on the Ravenswood shore is a massive hornblende gneiss or granite, which is thought to be intrusive.

Merrill,[87] in 1898, gives a general account of the geology of the crystalline rocks of southeastern New York.

The crystalline rocks lie east of Hudson River, in New York, Westchester, Putnam, and Dutchess counties, whence they extend into Connecticut; and west of the river, in Orange and Rockland counties, whence they extend southwesterly into New Jersey. The lowest member is a coarse hornblende granite, which forms the central mass of the range of mountains known as the Highlands of the Hudson, and, in their highest peak, Breakneck Mountain, is exposed through a vertical height of nearly 1,200 feet. Other granites, nearly free from hornblende, occur in subordinate masses. The granites are probably igneous and of great age. On their flanks are banded gneisses consisting chiefly of quartz and orthoclase, with biotite and hornblende, and containing numerous beds of magnetic iron ore. The gneisses on the south side of the Highlands extend through Westchester County in a series of folds with southwesterly trend, and on the northern slope of the Highlands, at several places in Dutchess County, are overlain unconformably by quartzites, which are believed to be of Cambrian age.

RIES,[88] in 1898, describes the geology of Orange County, N. Y. Pre-Cambrian rocks form the Highland region in the eastern part of the county, the northwestern side of Bellvale Mountain, and a series of rounded, knoblike hills extending from Sugar Loaf village to Newburg. They comprise gneiss, at times massive and resembling granite and limestone. The crystalline rocks are folded and faulted, the folds plunging frequently to the northeast.

In the south-central part of the county is found an area of white and blue limestone, which continues southward into New Jersey. The white limestone in New Jersey contains fossils of Cambrian age. About 1¼ miles west-southwest of Pine Island station, east of the road, are exposures which show the passage of the blue into the white limestone. Other similar areas of limestone are found to the northeast.

Limestones interbedded with the gneisses occur at Popolopen Pond and at Fort Montgomery.

VAN HISE,[89] in 1901, visited the area bordering Long Island Sound and other localities in southeastern New York. Just as in western New England, there is here present below the undoubted Cambrian and later sediments a basal complex of pre-Cambrian age. In the area about Long Island Sound this complex, mapped as Fordham gneiss, is as a whole a very evenly banded gray gneiss. In places it is remarkably like the pre-Cambrian gneiss of western New England; that is, it is a complex of white banded gneiss and black biotitic amphibolitic schist, both intricately cut by pegmatite. The crystalline Paleozoic sediments unconformably above this are also very similar to those of western New England, both lithologically and structurally. At the base is quartzite, above this limestone, and above this schist (the Manhattan schist), into which the limestone grades with interstratification. In this region also the Manhattan schist is locally found resting directly on the pre-Cambrian, due probably to overlap, change in sedimentation, or overthrust faulting, or possibly to some combination of these.

Locally, and especially in the area about Larchmont and New Rochelle, the Manhattan schist has been so completely metamorphosed and so intricately injected by igneous material that it is practically impossible to state whether or not sections of the pre-Cambrian core are here present, although it is agreed that the positive evidence is in favor of the whole being post-Cambrian. As bearing on this question, it is observed that where the undoubted Manhattan schist occurs both garnet and fibrolite are prevalent, and these are minerals which would be expected to develop during the metamorphism of an argillaceous sediment such as the Manhattan schist is believed to have originally been. On the other hand, where the Manhattan aspect is lacking, although garnet is present, the aluminum-silicate minerals are not found.

Merrill,[90] in 1902, describes the metamorphic crystalline rocks of the New York quadrangle. Of these only one, the Fordham, is of pre-Cambrian age. At the type locality this is a gray banded gneiss. The bands, which rarely exceed 2 inches in thickness, vary much in composition. Some are highly quartzose, some are composed largely of biotite, and some consist of pegmatite or granite which seems to have been injected parallel to the regular banding of the gneiss.

Eckel,[91] in 1902, summarizes the geology of the entire southeastern district, and advances a new view concerning the pre-Cambrian gneisses of the New York Highlands, separating them into four divisions, founded on lithology or composition, rather than on superposition.

Berkey,[92] in 1907, discusses the structural and stratigraphic features of the basal gneisses of the New York Highlands, and especially those of the Tarrytown and West Point quadrangles. These are not different in general characteristics from those described under the head of Fordham gneiss in the New York City folio (No. 83) of the United States Geological Survey, except that sediments apparently become more abundant northward. Broadly, the formation includes banded granitic, hornblendic, micaceous, and quartzose gneisses; mica, hornblende, chlorite, quartz, and epidote schists; garnetiferous, pyritiferous, graphitic, pyroxenic, tremolitic, and magnetic schists and gneisses; crystalline limestone, serpentinous limestones, ophicalcites, serpentine, tremolitic limestone, and quartzite; pyrite and magnetite deposits; granite and diorite gneisses; true granite, diorite, and gabbro bosses; numerous dikes, stringers, and lenses of pegmatite; and occasional basaltic, diabasic, and andesitic dikes. All of these occur with many variations and gradations, such as can be seen only in an area of extreme metamorphism and many dynamic disturbances. Many of the occurrences of gneisses, a few of the schists, and all of the granites, diorites, and gabbros are of igneous origin, but all occur as intrusions or injections—as sills, dikes, or bosses cutting the metamorphosed sedimentary members of the formation. No subdivision of the gneiss formation at present seems possible. There is no natural stratigraphic break. Because of the abundance and regularity of the igneous injections and the close folding and frequent faulting even the order of superposition of the constituent members is not clear. At a few places, in what seems to be an upper member, because of its connection with overlying formations, the banded black and white gneiss most characteristic of the series passes gradually and normally into a mica quartz schist, and this in turn into a rather pure quartzite, a few feet thick. The series has all the physical characters of the Grenville series of the Adirondacks and Canada and is so called.

Possibly unconformably upon but closely infolded with the Grenville series is the Inwood limestone. In the New York City folio this is regarded as conformable with the underlying series. The conditions may be those of overlap. This in turn is overlain conformably by the Manhattan mica schists.

Intrusive into the Manhattan schists and Inwood limestone are basaltic, diabasic, granitic, and other intrusives. Both are believed to be overlain unconformably by the Poughquag quartzite, of Cambrian age. They have before been correlated with the Wappinger limestone and Hudson River slates. While no unconformable contacts have been actually observed, the Inwood limestone is coarsely crystalline, whereas the Wappinger is fine; it is very impure with silicates and pegmatites, and has occasional dike intrusions and strong epidotic development, whereas the other has none; there is no quartzite on either margin of the Sprout Brook (Inwood) limestone and none beneath it, as may be seen by following up the brook to the point where the limestone disappears, whereas the other has at least 500 feet of quartzite conformably beneath. For more than a mile this crystalline limestone occupies the valley for a width of at least one-fourth mile. It is well developed for a distance of more than 6 miles. It must be, at the lowest estimate, several hundred feet thick. Farther up the valley, where the limestone disappears, only gneisses of typical Highland types remain. It is clear that the limestones of these two adjacent valleys can not be the same. The Sprout Brook representative is much the older.

STEWART,[92a] in 1908, discusses the magnetite belts of Putnam County, N. Y., and shows their similarity to magnetites of the Highlands of New Jersey described by Spencer, Bayley, and others. Details of Grenville geology are discussed.

SUMMARY OF PRESENT KNOWLEDGE.

Contrasting views of the classification of the crystalline rocks of southeastern New York are held by Spencer, Eckel, Bayley, and Merrill on the one hand, based on work of Eckel and Merrill in the New York City quadrangle and of Spencer and Bayley in New Jersey, and on the other hand by C. P. Berkey, who has been mapping the

Tarrytown and West Point quadrangles in the Highlands of New York. The first view is presented by Spencer as follows:

View of A. C. Spencer and associates.—In southeastern New York is a great series of crystalline rocks which are now generally regarded as of pre-Cambrian age. These rocks include granites and granite gneisses, syenites, evenly banded schistose gneisses, bedlike bodies of magnetic iron ore, and interlaminated masses of crystalline limestone. East of the Hudson River they are found in New York, Westchester, Putnam, and Dutchess counties, whence they extend into Connecticut, and west of the river in Orange and Rockland counties, extending thence southwest into New Jersey. A coarse hornblende granite forming the central mass of the Highlands of the Hudson is believed by Merrill to be the oldest formation of the complex, but later work by Eckel tends to show that relations of superposition can not be recognized. This suggestion corresponds with recent work by Bayley and Spencer in New Jersey, where the gneisses are regarded as mainly eruptive. On the flanks of this mass of granite are banded biotitic and hornblendic gneisses containing numerous beds of magnetite. These gneisses are found, both north and south of the Highlands of the Hudson, to be overlain unconformably by Paleozoic sediments. The Fordham gneiss of Westchester and New York counties is also overlain unconformably by Paleozoic formations, but it has not been correlated as yet with any part of the complex in the Highlands of the Hudson.

Infolded with the gneisses along northeast-southwest axes are highly metamorphosed and crystalline Paleozoics. The folds are closely compressed—often overturned. The general dip of schistosity is toward the southeast, though faulting and transverse folding cause local variations. The crystalline sediments of southeastern New York, including the "Manhattan group" and the "Taconics," are now regarded mainly as the metamorphosed equivalents of the Cambrian and Ordovician formations which occur in an unaltered condition north of the Highlands. With them are associated intrusive rocks and the pre-Cambrian Fordham gneiss.

View of C. P. Berkey.—Berkey finds in the basement gneiss group, northward from New York, limestones and other sediments with such relations to the gneiss as to lead him to correlate the group with the Grenville series of the Adirondacks and southern Ontario. This correlation he believes also to extend southward into the New York City quadrangle. A part of the supposed Paleozoic rocks called the "Inwood" limestone and "Manhattan" schist, infolded with the basal series, he finds to be pre-Cambrian and to be separated by an unconformity from the Poughquag quartzite above, representing the base of the Paleozoic, and by another unconformity from the basement gneiss series below. He says that if these rocks are truly conformable with the basal gneisses in the New York City quadrangle, the difference in the apparent relations in the two areas may be explained by partial overlap.

SECTION 3. HIGHLANDS OF NEW JERSEY.

SUMMARY OF LITERATURE.

Vanuxem and Keating,[93] in 1821, state that the country around Franklin is composed of syenite, which is found in beds or layers of variable thickness, running in a direction parallel to that of the ridge. A white limestone forms a bed with eminently crystalline structure, the inclination, direction, and dip of which are the same as those of the syenite. This limestone has been traced for a distance of 8 miles, and, although the limestone is subordinate to the syenite, masses of the latter are found in it. At Franklin, next to the syenite, are found masses of graywacke, which, on the road from Franklin to Doctor Fowler's, is seen to be superimposed upon the syenite and is evidently a later formation. About a quarter of a mile below the furnace it is covered with a violet limestone, which rests upon it in parallel superposition. This limestone and that associated with the syenite are not of contemporaneous origin, but the blue limestone is a real mantle-formed superposition.

Pierce,[94] in 1822, describes the Highland ranges as Primitive, with the exception of an isolated Transition region. The rocks here included are granite, gneiss, and syenite, while in the Transition are found graywacke, graywacke slate, chlorite slate, and limestone.

Rogers (H. D.),[95] in 1840, gives a systematic account of the Primary rocks of New Jersey. These are almost exclusively of the stratified class, consisting of gneiss under all its forms, the granitoid variety predominating. Innumerable small veins of feldspathic granite, syenite, greenstone, etc., penetrate the gneiss. The gneiss is comparatively seldom of the schistose kind. Mica is deficient, the usual mixture being either feldspar or quartz with a little mica, or these minerals with an excess of hornblende, and hornblende and magnetic oxide of iron, the latter being so abundant as to be a characteristic constituent. It occurs not only as an occasional ingredient of the gneiss, but in great dikes or veins penetrating the strata. The massive granitoid gneisses of the Highlands are in striking contrast with the gneiss belt of New York and Staten Island, which reappears at Trenton and ranges through Pennsylvania and Maryland, which is distinguished by the prevalence of mica and other thinly laminated minerals, imparting to the rock a schistose structure or the thinly bedded character of ordinary gneiss. The massive strata are, on the whole, decidedly less extensive than in the Philadelphia belt. They are usually highly inclined, the average dip exceeding 45°. In many of the principal ridges an anticlinal arrangement is plainly visible.

There are three main axes of elevation in the granitic area rising above the Secondary sandstones and limestones. The metalliferous veins generally coincide with the direction of the strata in strike and dip, but they exhibit many minor irregularities, such as frequent change in thickness and deviation from the direction of the strata, and are regarded as unchanged matter. The gneiss formation of Trenton has a steep inclination, about 70° SE., rests unconformably under the more recent formations, and is regarded as the equivalent of the gneiss of Manhattan Island.

The blue limestone belonging to the older Secondary strata has often a secondary cleavage corresponding with the slate to which it is adjacent. Associated with these limestones are various igneous rocks, which have locally caused it to become crystalline and have developed within it plumbago and various silicates. Often these crystalline forms of limestones are associated with the metalliferous veins, which are regarded as the cause of their crystalline character.

JACKSON,[96] in 1854, maintains that the New Jersey crystalline limestones are of igneous origin.

KITCHELL,[97] in 1856, places the formations of the Highlands in the Azoic system. These include gneiss, hornblendic, micaceous, feldspathic and quartzose schists, and white crystalline limestone interstratified with seams or layers of magnetic iron ore. These rocks are traversed by numerous intrusive dikes of granite and syenite; the strata are highly metamorphic; they exhibit violent dislocations; their general strike is northeast and southwest, the same as the intrusive dikes, and their dip southeast. In addition to their distinct stratification they exhibit planes of cleavage, frequently at right angles to the former and generally inclining toward the northeast at all angles up to 45°. At one place limestone rests unconformably upon the gneiss.

COOK,[98] in 1868, places under the Azoic rocks the gneisses, crystalline limestone, and beds of magnetic iron ore. The crystalline limestone in every case is conformable to the gneiss and interstratified with it. It is not, as supposed by Rogers, the metamorphosed blue limestone. The iron ores, instead of being igneous, are believed to be true beds, which were deposited as sediments in the same way as the material of the gneiss rocks. The gneiss is divided into four principal belts. The Azoic formations, with trifling exceptions, are stratified. Usually they are highly inclined, but they vary between horizontal and vertical. The axes of the folds are generally in a northeast-southwest direction. Some of the rocks are so thin bedded as to be schistose, while other portions are so thick bedded that for long distances it is almost impossible to tell which way the rock dips. The gneiss is cut by veins and dikes of trap and granite. The Azoic rocks of

Trenton are much more like a true gneiss than those of the Highlands. The Potsdam sandstone, the base of the Paleozoic, is found resting unconformably upon the Azoic gneiss at Franklin Furnace and at Green Pond Mountain. The relations of the two rocks are such as to make it certain that the sandstone is later than and unconformably upon the gneiss. The Franklin Furnace sandstone is capped by the blue magnesian limestone, which is equivalent to the Calciferous sandstone of the New York reports.

Cook,[99] in 1873, gives the four Azoic belts of New Jersey the names Ramapo, Passaic, Musconetcong, and Pequest. In the first and last are found numerous bands of interlaminated limestones, but in the others these are not known to occur. Lithologically the greater portion of the Azoic rock is syenite gneiss. There is no way of identifying it with the Laurentian or Huronian of Canada. As to origin, all are agreed that these Azoic syenitic gneisses are sedimentary. The crystalline limestone of the Ramapo belt is associated with the serpentine, sometimes in large quantity.

Cook,[100] in 1883, states that the rocks of the Highlands include granite, syenite, several varieties of gneiss, crystalline limestone, and magnetite, with rare species of various schists and some serpentine. The strata dip to the southeast at an angle of 45° to 80°, although it is often difficult to determine the directions of strike and dip positively because of the massive character of the rock. The ranges are regarded as anticlinal folds in general, although this is probably not true in every case, and the valleys are synclinal. The massive syenites, granites, and traps are very limited in quantity, and are perhaps a part of the stratified beds in which stratification has been obliterated, although granite and syenite dikes are found traversing the bedded gneisses.

Darton,[101] in 1883, states that at Sparta granite cuts across the limestone beds and may be in true veins.

Cook,[102] in 1884, finds that besides the southeastern dips northwest dips occur. There is difficulty in separating the stratified from the unstratified rocks, as nearly all the glaciated ledges look like massive rocks. The relations of the syenite rocks and gneisses are not made out and it can not be asserted which are the older, but these granitoid and syenitic rocks are surrounded by stratified gneisses and other crystalline rocks. To the Highlands the term Archean is applied because it does not necessitate any correlation or theory, as would the use of Laurentian or Azoic.

Britton,[103] in 1885, states that few, if any, of the ridges are simple anticlinal folds, the southeast dips being generally as prevalent on one side of the mountain as on the other, though often differing perceptibly in degree. The crystalline limestones do not represent the blue magnesian limestone metamorphosed by granite and syenite. The supposed dikes of granite are strata conformable to the white limestone, as are the iron and zinc ore beds contained in it, all geologically older than the blue limestone with the quartzites and slates composing the Lower Silurian system. The conclusion is now reached that the unstratified rock masses underlie the bedded crystalline rocks, although the line of separation is but poorly defined, as the stratified rocks of the same mineral composition commonly occur on the sides of the massive area, with an apparent gradual passage between the two, and at no point was any actual unconformity found, although at some places abrupt changes in the lamination were observed within short distances. This leads to the conclusion that the massive beds are so only because stratification has been wholly destroyed through greater metamorphism. The schistose series commonly have a steeper dip along their southern margins than along their opposite sides; thus the axial planes of the folds are often inclined toward the southeast.

While the Potsdam and Paleozoic rocks are unconformable upon the Archean, the newer rocks are tilted in such a way as to show that folding has occurred since they were deposited. At only a few places are actual junctions found, the two more important being in Owens Island, in Sussex County, and at Franklin Furnace. At several localities the relations are perplexing, for the quartzites and conglomerates are so heavily feldspathic that near the junction they appear to grade gradually into the older rocks, fragments and masses of which are included in them. Along the southeastern margin of the Highlands the Silurian is crystalline, including crystalline limestones and hydromica slates, and here the unconformity is much less pronounced, no satisfactory contacts being known in New Jersey. At Pompton the slate ledges have nearly the same dip and strike as the nearest Archean outcrops. At Peekskill Hollow and Annsville Cove, in New York, the slates and quartzites and crystalline rocks appear to be directly conformable, the strata having been subjected to an overturn that caused the quartzite to dip under the older rocks, and it is difficult to say where the line of separation is.

MARTIN,[104] in 1886, states that the Tidewater gneiss has mineralogical characters which distinguish it strongly from the gneisses of the northern Laurentian and from the Highlands. In particular the abundance of subsilicates and of hydrous silicates is to be noted.

BRITTON,[105] in 1887, divides the Archean rocks into a massive group, an iron-bearing group, and a gneissic and schistose group, which is also believed to be the order of superposition, although there is a gradual change from one sedimentary rock into the other. While the massive rocks are but faintly laminated, there is no evidence adducible in favor of an igneous origin for them, but all indications point to their deposition as sediments of one kind or another, and to the more or less complete obliteration of the bedding planes by excessive metamorphism. The beds of magnetic ore occur in different horizons of the middle group, but never in the highest or lowest. In this same group the beds of crystalline limestone appear generally to be at a slightly higher horizon than the magnetite beds. The highest gneissic and schistose group corresponds very well in character with the Montalban system of Hunt. These rocks are like those of Trenton and Westchester counties in New York. Among the eruptive rocks are placed those which occur in dikes, such as diorite, diabase, kersantite, and porphyry.

Britton,[106] in 1888, describes as occurring in the Archean of New Jersey an organic form, apparently algæ, to which he applies the name *Archæophyton newberryanum*.

Nason,[107] in 1890, describes the Archean of New Jersey. Here are found four types of rock: The Mount Hope type, a foliated magnetitic gneiss, the magnetite sometimes largely replaced by hornblende, with little mica; the Oxford type, foliated hornblende gneiss, magnetite and biotite in places almost wholly replacing the hornblende; the Franklin type, a less foliated biotite gneiss; and the Montville type, white or crystalline limestone. The Franklin type differs from the Mount Hope and Oxford types in that the quartz and feldspar are usually in sharply angular grains, which contrast with the roundish grains of these minerals in the first two types. The crystalline limestone is placed under the Archean only provisionally. As there are apparently many reasons why it should be considered of more recent origin, there is greater reason for supposing that if a part of it proves to be Archean all will not. This rock is found at Montville, Wanaque, Pequest Furnace, Jenny Jump Mountain, Oxford Church (now Hazen), and Mendham. No actual contacts between the different groups have been found. The distribution of the various types is described in detail. Whether the gneisses are sedimentary or eruptive has not been ascertained, but there are many localities in which true eruptive granitic rocks inclose within their masses fragments of the adjacent schistose and gneissic rocks. Also in the Archean is frequently found gabbro, which is almost certainly of igneous origin. Occurrences of graphite are widely separated in the Archean rocks. At one place, commencing at the old graphite mine near South Bridge, it is found continuously for 35 miles. A similar rock has been found at Iona Island in Hudson River, 35 miles northeast. Another line is found on Bald Hill, and a third graphite gneiss is found on a hill east of Pompton station and in part of the Ramapo Mountain range. Graphite occurs at other places, also.

Nason,[108] in 1891, describes the relations of the white and blue limestones of Sussex County, N. J. They are found to grade into each other at many points. The white limestone is always associated with later granitic eruptions. In passing away from a boss or dike the limestone is white, but changes steadily with rapid gradations into the blue limestone. Sandstones and quartzites of identical character underlie both the white and the blue limestone and bind them together. The one distinguishing fact which separates the white from the blue limestone is the presence of eruptive rocks. It is therefore concluded that the two are identical. As the blue limestone belongs to the Cambrian, it is concluded, contrary to what has been supposed, that in this region there are no Archean limestones.

Kemp,[109] in 1903, describes the ore deposits at Franklin Furnace and Ogdensburg, N. J., and briefly sketches the general geology of the area. The ore deposits occur in white crystalline limestone, which is cut in numerous places by dikes of granite, trap, and a rock taken to be altered gabbro. The white limestone is closely involved throughout its extent with a blue limestone of Cambrian or Cambro-Silurian age.

Nason,[110] in 1894, finds as a result of analyses that the white and blue limestones of Sussex County, N. J., are essentially the same in composition, both being magnesian limestones or true dolomites. The coarsely crystalline white limestone near its contact with granite is generally nonmagnesian.

Nason,[111] in 1894, gives a summary of facts showing that the white limestone of Sussex County, N. J., is of Cambrian age, as follows: (1) The white limestones are continuous with the blue limestones (now accepted as of Cambrian age), and every degree of transition may be found between them. (2) Both have the same strike and dip. (3) Both are conformable with a quartzite also containing Cambrian fossils. (4) Both are unconformable with the gneiss upon which they rest. (5) Both have in sum total the same chemical composition and are magnesian. (6) The altered crystalline condition of the white limestone is due to the intrusion of igneous masses and to regional metamorphism, while the blue limestone never contains such igneous injections. (7) The presence of certain minerals, especially chondrodite, is not indicative of geological age, as this mineral is known to occur in modern volcanic rocks.

Westgate,[112] in 1894, holds that the crystalline limestones of Warren County, N. J., are distinct from and older than the blue magnesian limestone and are of pre-Cambrian age, for the following reasons: They have a well-developed crystalline character, and hold large quantities of accessory metamorphic minerals; they show no intimate association with the blue Cambrian limestones; they show no tendency to grade into them; they have been subjected to general metamorphic forces, of which the neighboring blue limestone shows no trace; they occur in intimate association with the granitoid gneisses, and in some cases appear to be interbedded with them.

WOLFF,[113] in 1895, reaches the following conclusions as a result of his detailed study of the Highlands of New Jersey in the vicinity of Hibernia. The rocks are found to consist of distinct bands of gneiss which can be recognized. These layers have once been nearly horizontal, and are folded into an anticlinal dome which has the characteristics of ordinary folds and a distinctly recognizable pitch. The rocks of the series have a top and a bottom, the bottom rocks being at the center of the dome and the top rocks at the periphery. One characteristic horizon, a garnet-biotite-graphite gneiss, must once have existed over a large part of the present area, and the same is probably true of the lower horizons. The foliation, in part at least, is parallel to the bounding planes of the different layers of rocks. The crystallization of the rock occurred during or after the action of the compressing force which folded the rocks and produced pitch, but not before, since this structure is inherent in the shape of the minerals as they crystallized. These facts favor the view that the series is a sedimentary one, in which metamorphism and recrystallization took place contemporaneously with the folding and without fusion, and therefore that it is of Algonkian age.

WESTGATE,[114] in 1896, describes and maps the geology of the northern part of Jenny Jump Mountain, in Warren County, N. J. The main ridge of the mountain is formed chiefly of gneisses, comprising many varieties. These are, from northwest to southeast, and also, according to the banding, from base to top, (1) granitoid biotite-hornblende gneiss, containing narrow bands of biotite-hornblende gneiss; (2) hornblende-pyroxene gneiss; (3) biotite gneiss; (4) dark biotite-hornblende gneiss; (5) granitoid biotite-hornblende gneiss; and (6) dark biotite-hornblende gneiss and gray micaceous gneiss. Certain of the dark hornblende gneisses have been so extensively altered as to be called epidote rocks. The gneisses are in general granitoid and massive, and there is a conspicuous absence of schistose rocks and crumpling of the banding, the banding over wide areas having uniform strike and dip.

Along the southeast side of the mountain, at the northeast end of the mountain, and in two isolated outcrops within the gneisses of the main ridge are areas of white crystalline limestone. The limestone is in all cases closely associated, and perhaps interbanded, with the dark biotite-hornblende gneiss and gray micaceous gneiss (Nos. 4 and 6 above), and at the northeast end of the mountain also with quartz pyroxene rock.

Cutting both gneisses and limestone are pegmatite, diabase, and amphibolite or granular diorite.

The origin and age of the gneisses are doubtful. The presence of limestone belts closely associated and perhaps interbanded with the hornblendic and micaceous gneisses, and the presence of magnetic iron ore, suggest a detrital origin for at least a part of the gneisses, and consequently their reference to the Algonkian. A part of the hornblende gneisses associated with the limestones is also recognized as igneous, and attention is called to the similarity to hornblende gneisses occurring within the light-colored rock making up the main mass of the mountain. There may be really two series of rocks: (1) A series of limestone and associated interbedded rocks, of sedimentary origin, and (2) a series of more massive granitoid gneisses, probably older, and of unknown origin. This supposition is based only on the fact that the limestones are persistently associated with the hornblendic and micaceous gneisses and quartz-pyroxene rock, and are not found associated or in contact with the light-colored granitoid gneisses which constitute the main mass of the mountain. However, there is not sufficient evidence to refer a part of the gneisses to the Algonkian, and all are therefore classed as pre-Cambrian.

The crystalline limestones are believed to be distinct from and older than the blue magnesian limestone of Cambrian age which occurs along the northwestern side of the New Jersey Highlands and which outcrops in isolated areas in the valleys adjacent to Jenny Jump Mountain, for the following reasons: (1) They differ lithologically from the blue limestone in being thoroughly crystalline and in containing large amounts of accessory metamorphic minerals, showing that they have been subjected to general metamorphic forces of which the neighboring blue limestone shows no trace. (2) They occur in intimate association with the gneisses, which are of admitted pre-Cambrian age. (3) They show no intimate association in areal distribution with the blue limestone, nor any tendency to grade into it. (4) The metamorphic changes to which the white limestones have been subjected are general in their nature, and not due to the action of eruptives by which they are cut; so that no sufficient agent is at hand to account for the supposed change from blue into white limestone. The white crystalline limestones are therefore believed to be of pre-Cambrian age.

Wolff and Brooks,[115] in 1898, present a final discussion of the age of the Franklin white limestone, of Sussex County, N. J. The pre-Cambrian age of the white limestone is believed to be shown by the following facts:

The supposed cases of interbedding of the white limestone and the Cambrian quartzite are found to be due to faulting or to peculiar conditions of deposition. On the other hand, while it is difficult to prove that the white limestone and the pre-Cambrian gneiss are actually interbedded, narrow bands of the true gneiss do occur within the white limestone belt, and seem to be an integral part of the series.

The granite occurring in the area is intrusive in the white limestone, and the nature of the contacts of the granite and the Cambrian quartzite indicates that the intrusion was prior to the deposition of the Cambrian quartzite and the blue limestone. While the intrusion of the granite has caused local metamorphism of the white limestone, it is believed that the crystallization of the limestone antedated the granitic intrusion and was contemporaneous with the crystallization of the gneisses in their present form.

The structural relations of the three belts of Cambrian blue limestone with the gneiss and the white limestone are such as to indicate unconformity. Along the normal contacts of the blue and the white limestones the quartzite intervenes between the two. The bedding of the blue limestone and the underlying quartzite is everywhere conformable, while the dip of the foliation of the white limestone and the gneisses is discordant with this bedding.

Isolated patches of Cambrian quartzite are found within the white limestone area. In one place a crevice in the white limestone is filled with the Cambrian quartzite containing undoubted pebbles of the white limestone.

Spencer,[116] in 1904, regards the crystalline rocks of the New Jersey Highlands, excepting the white limestone, as intrusive. He believes their gneissic structure an original feature of their first consolidation, and not due to metamorphism. In Sussex County there are several fairly distinct types of crystalline rock, all of which are stated to be intrusive with respect to the white limestone, though among themselves the relations are often indeterminate. The reason for this seems to be that the different rocks became mixed or interlarded while still in a noncrystalline or magmatic condition. Three types of gneissoid rock are separated on the basis of color and mineral composition. In different places two of these types are found intrusive into the white limestone, while the third, a white rock characterized by oligoclase, is also evidently later than the limestone, since it cuts one of the others. Pegmatite occurs in large and small masses inclosed in all of the other crystalline formations. Grains of magnetite occur in all of the igneous rocks, and shoots of ore are inclosed by all of them and also by the limestone; but pegmatite is always encountered in greater or less amounts wherever there is any large amount of magnetite. It is concluded that the masses of magnetite were segregated during the invasion of the pegmatite dikes.

Spencer,[117] in 1905, considers all the well-marked types of gneiss occurring in the Franklin Furnace quadrangle as of igneous origin. The pre-Cambrian rocks are grouped under five heads: (1) The white limestone; (2) a complex of light-gray and dark-gray gneiss; (3) black hornblende and pyroxene gneiss; (4) white granite gneiss; and (5) pegmatite. This order represents the general age relations, which are shown as follows: Pegmatites are found cutting all of the other rocks in the district; the white gneiss cuts the two remaining gneisses; and the black rock cuts the gray gneiss and the limestone. The age relations between the light-gray and the dark-gray gneisses have not been determined, and only the former has been found cutting the limestone. So far as observation goes, the limestone may be infolded with the dark-gray gneiss. An intimate association between the magnetic iron ores and the pegmatites leads to the conclusion that the two are connected in origin.

Bayley,[118] in 1908, maps and describes the pre-Cambrian geology of the Passaic quadrangle of New Jersey and New York, which includes a part of the New Jersey Highlands in its northwest corner. Lithologically the rocks of the Highlands in the Passaic quadrangle, like those of the Highlands elsewhere, are mainly granitoid gneisses and pegmatites with subordinate amounts of magnetite and of garnetiferous graphite schist. In one locality, on Turkey Mountain, north of Montville, there is a small exposure of white marble which contains nodules of serpentine; and on Copperas Mountain there are conglomerates and quartzites. The limestone is correlated with the Franklin Furnace limestone because of similarity in lithology and relations to gneisses. It is certainly pre-Cambrian, but whether Algonkian or pre-Algonkian has not been determined. The associated gneisses are grouped into three lithological types, the Losee gneiss, the Byram gneiss, and the Pochuck gneiss. Rarely does one type alone occupy any large area, but each occurs variously mixed with others in long, narrow belts wedging out at their ends. The genetic relations of the three are largely unknown, though part of the dark Pochuck gneiss is older than the other two gneisses, which are acidic. The acidic gneisses and a part of the Pochuck gneiss are intrusive into the Franklin limestone, and all are in turn intruded by pegmatites. No evidence has been discovered in the Passaic quadrangle that would lead to a decision as to the original condition of the older Pochuck gneiss, but from consideration of the phenomena observed in the Adirondacks and eastern Canada, where the geologic conditions appear to be nearly identical with those prevailing in the Highlands of New Jersey and where rocks very closely resembling the Pochuck gneiss appear to be metamorphosed sediments, without doubt, it is thought possible that some of the older rocks classified as Pochuck gneiss in New Jersey may have had this origin. The general structure is monoclinal with northeast-southwest strike and southeast dip, but individual layers or groups of layers are sharply corrugated.

Spencer,[119] in 1908, maps and describes the pre-Cambrian rocks of the Franklin Furnace quadrangle of the Highlands of New Jersey. These rocks are similar to those described by Bayley for the Passaic quadrangle, immediately to the southeast. The pre-Cambrian rocks are gneisses and limestones of Grenville type, dipping monoclinally southeastward. Straight or gently curving structural features are the rule, but in many places individual layers or sets of layers, if followed along the strike or along the dip, exhibit at intervals sharp, troughlike corrugations. These corrugations range in size from mere wrinkles to folds of considerable span. Two of the lithological units are called the Losee gneiss and Byram gneiss. They are acidic igneous rocks intrusive into the rocks with which they are associated, and occupy a larger area than the other rocks of the group. Less abundant than the granitoid rocks, but still of considerable importance in the field at large, is the dark Pochuck gneiss. The rocks embraced under this term have the composition of igneous diorites or gabbros, but whether they have been derived from igneous or sedimentary originals, or, as is thought, in part from both, their present characteristics have in most places been acquired by metamorphism, involving secondary crystallization.

These rocks are invaded by irregular dikelike masses of pegmatite which have a genetic relationship with the magnetite deposits.

SUMMARY OF PRESENT KNOWLEDGE.

The following summary has been prepared for this bulletin by Arthur C. Spencer:

Occupying most of the New Jersey Highlands are crystalline rocks resembling those of the adjacent part of New York and bearing such relations to the Cambrian sandstone as to indicate a great structural break between them. The rocks of the area consist largely of granitoid gneisses showing several mineralogic types. Though in many places they appear to be nearly massive, there is usually a laminated arrangement of the mineral constituents. The strike of the lamination and of the bands of different gneisses conforms to the trend of the area as a whole, being east of north and south of west. Interlayered with the gneisses are tabular masses of limestone and bedlike bodies of magnetic iron ore. Certain bands of the gneisses are graphitic. All of these are cut by various acidic and basic eruptives, the former being of pre-Cambrian age and the latter mainly but not entirely post-Cambrian. In several places the white limestones occur in proximity to the blue limestones of Paleozoic age, and there has been much discussion as to the relations of the two. Wolff and Brooks have, however, definitely proved the pre-Cambrian age of the white limestone occurring in the Franklin Furnace belt, and the same conclusion is ably argued by Westgate for the similar limestones on Jenny Jump Mountain. The pre-Cambrian age of the white limestone in this area must be accepted for the northern end of the same belt, which extends into New York State.

The weight of opinion in former years has been in favor of the sedimentary origin of the gneissic series. The development of this hypothesis reached its culmination in the work of Britton (1885 and 1887), who describes the more massive and the markedly foliated rocks, and, dividing the whole series into three groups, states their order of superposition as follows: (1) Massive group, (2) iron-bearing group, (3) gneissic and schistose group. Nason shows (1890) that Britton's groups are not mutually exclusive and negatives his suggestion of superposition. Agreeing, however, that Britton has demonstrated the possibility of dividing and mapping the foliated Archean rocks, Nason selects four lithologic types believed to be so constant in general appearance that they can be recognized in widely separated areas. These types are not to be taken in any sense as dividing the Archean into groups. The author believed that, having fixed these types, other rocks with less marked characteristics would eventually be separated. The avowed purpose of Nason's method was to approach the problem without bias, leaving hypotheses of origin aside until the facts of composition and distribution should be ascertained.

Wolff regards the gneisses which inclose the bed of iron ore at Hibernia as sedimentary because they contain graphite, and especially because they show a folded structure. From this structure he argues that the gneisses in the vicinity are definitely bedded, with top and bottom, and that the ore bed lies in conformable position with the layers of gneiss. On the other hand, an igneous origin for the gneisses of Sussex County, in the New Jersey Highlands, is supported by Spencer. Recent work by Bayley[a] and Spencer (Raritan, Passaic, and Franklin Furnace quadrangles) leads them to the conclusion that the gneisses are mainly igneous, later than the white crystalline limestones, and that the gneissic structure is essentially not due to secondary dynamic pressure, but is a primary feature of the rock, acquired during intrusion and consolidation. Nevertheless, large but indeterminate amounts of gneiss are supposed to represent sediments which were very completely granitized during the invasion of the igneous material, and the bulk of the magnetite iron ore is thought to have been formed mainly as metasomatic replacements of sedimentary rocks brought about during the general metamorphism. A minor part of the iron ore is connected in origin with later intrusions of pegmatite. The several types of gneiss recognized are not correlated with those described by Nason, though their separation is made upon similar grounds. They can not be mapped in an entirely consistent manner, because of intimate interlamination and a certain amount of gradation; but mapping is possible upon the basis of preponderance of the several types in different areas. This work, if

[a] Manuscript summary of unpublished work furnished by Arthur C. Spencer, 1906.

eventually accepted, will place the pre-Cambrian rocks of the Highlands of New Jersey and southeastern New York in the same light as the Grenville rocks of the original Laurentian region and the similar formations of the Adirondacks, in both of which regions the main part of the gneisses of determinable origin is regarded as intrusive by Smyth, Adams, and others. In this case the Algonkian or Archean age for New Jersey must be determined upon the final correlation of the white crystalline limestones and of the other sediments occurring with or near them in minor amounts. However, as in the regions mentioned above, failure to find or recognize a basal complex upon which the limestones and other remnants of sedimentary rocks were deposited can not be accepted as evidence that the basement is not somewhere represented.

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CHAPTER XI.

PIEDMONT PLATEAU AND ADJACENT PORTIONS OF THE APPALACHIANS IN ALABAMA, GEORGIA, TENNESSEE, NORTH CAROLINA, SOUTH CAROLINA, VIRGINIA, MARYLAND, PENNSYLVANIA, AND DELAWARE.

SECTION 1. PENNSYLVANIA.

SUMMARY OF LITERATURE.

FINCH,[1] in 1824, finds, near Easton, syenite, serpentine, and Transition limestone, Transition granite, Transition clay slate, and Transition sandstone.

FINCH,[2] in 1828, finds a section from Chads Fork to Westchester to include gneiss, mica slate, hornblende slate, Primitive sandstone, and Transition quartz rock.

ROGERS (H. D.),[3] in 1858, gives a systematic account of the metamorphic rocks of Pennsylvania. These are divided into three main divisions—the gneissic series proper, or Hypozoic; Azoic, or those destitute of relics of life, and Paleozoic. The Hypozoic rocks only are placed with the Primary. The Azoic schists are regarded as newer than the Hypozoic, because of differences in the position of the two sets of strata, in condition of metamorphism, and in manner of plication. The former dip almost invariably to the southeast, while the gneiss in many localities has no symmetrical folding. These dissimilarities imply essential differences in the directions and dates of the crust movements. The Azoic rocks, however, when they show the maximum amount of metamorphism, simulate in mineral aspect and structure those of the gneissic series. The old strata are then separated into three systems by two main horizons, the lower, a physical break between the Hypozoic and the Azoic; the upper, a life limit denoting the first advent, so far as discovered, of organic beings.

The gneissic rocks are separated structurally into three districts: First, the area running southwestward from Trenton, through Philadelphia; second, the area between the Schuylkill and the Susquehanna, north of the first area; and, third, the South Mountain region, a continuation of the Highlands of New Jersey. The Philadelphia belt is intersected very extensively by eruptive rocks, such as granite, greenstone, syenite, and trap. The second or middle belt is sometimes called the mica schist belt, because of the amount of this mineral which it contains. The upper or northern belt of gneiss is regarded as a part of the lower Primal rocks and as resting unconformably upon the upper gneissic group, the belief being based upon the manner of the flexure of the two formations rather than upon actual unconformable contacts.

In the Philadelphia belt there is a general prevalence of the northward dip of the strata, varying generally from 30° to 50°. At Fairmount the true dip of the rocks is very steep, although there is a deceptive appearance of a nearly horizontal stratification in thick and almost parallel beds; but this is not to be confounded with the genuine stratification or grain of the rock as marked by the general distribution of its mica and other minerals. In this belt there are really two groups of rocks, which, viewed broadly, constitute one synclinal wave. The lower is a harder feldspathic and hornblendic gneiss at the south side, dipping northward, and reappearing in steep and multitudinous contortions on the other side of the trough; and the upper is a more micaceous group filling the synclinal center of the trough and compressed into lesser folds.

In the middle division the rocks are mostly of the granite-like varieties of feldspathic gneiss, with hard hornblendic gneiss, such as constitute the central ridges of the South Mountain. These are believed to be in a series of anticlinal and synclinal waves, and in addition to the folds there is a series of folds along which the iron-ore deposits are found in V-shaped masses.

The northern or South Mountain zone is composed either of massive or thick-bedded gneisses, with which is no talcose slate, or else of the Primal white sandstone, the lowest member of the Paleozoic. The limestone associated with the gneisses is generally found in the synclinal valley. The gneisses are regarded as stratified; they dip to the southeast, and, as the breadth of the chain is so great, the structure is believed to be due to overturned flexures.

In the Delaware section is found the best evidence of unconformity discovered between the semicrystalline rocks called Primal and the gneiss. In one case here the Primal siliceous slates and quartzites are a porphyritic and crystalline quartzose conglomerate. Below this is an arch or wave of granitoid gneiss containing injections of syenite; and the dip of the gneiss seems also to be steeper than that of the Primal conglomerate. The relations are, however, best seen at Durham Creek. Here at one place the sandstone, slates, and conglomerates rest with their beds almost perpendicular to the lamination of the gneiss.

The lower part of the Paleozoic rocks consists of Primal crystalline schists, or the Azoic group; Primal conglomerate; Primal older slate; Primal white sandstone, and Potsdam of New York. The Primal series contains but few eruptive rocks, even trap dikes being uncommon, which is regarded as proving that the metamorphism is due to heated gases rising through fissures rather than to the contact of igneous material.

The Primal southern belt is first considered. At Attleboro there is no marked discordance between this and the gneissic series which is supposed to be older. East of the Schuylkill and in Montgomery County the observer is very liable to confound the lowest Primal beds with the uppermost hornblendic feldspathic layers of the adjacent genuine gneiss. West of the Schuylkill the Primal slates are of so crystalline a character that it is sometimes difficult to distinguish the strata from certain forms of the more micaceous beds of the true gneissic or Hypozoic. It is impossible to subdivide the members of the lower Primal group in southern Pennsylvania, because of a prevailing transverse cleavage, which extensively effaces all clear traces of the original bedding; because of the presence of innumerable plications, often so closely compressed as to appear as only one uniform dip, the anticlinal and synclinal foldings in many cases escaping detection through the obscuring influence of cleavage; and because of mutations in the composition of the beds. The rocks between the Primal white sandstone and the genuine gneiss then include talcoid siliceous slate, talco-micaceous slate, and schistose and quartzose micaceous rock. On the Brandywine the massive gneisses and finely laminated material are interlaminated in such a way as to lead to the conclusion that the latter are closely infolded in the older metamorphic series. In the Primal of Susquehanna and York counties the true bedding is very obscure, being almost obliterated.

In going southward along the Susquehanna one finds the rocks becoming steadily more crystalline, until they are so altered as to have been hitherto mistaken for the true Hypozoic. The precise line of contact of the limestones with the slates is not clearly visible at times; indeed, there seems to be no line of sudden transition. The cleavage planes are in general parallel with those of the original bedding. The dips on this river are steadily in a southeast direction for a distance of 7 or 7½ miles, and it is believed that the rocks consist of many compressed folds which repeat the same strata many times. Southwest of the Susquehanna, in the South Mountains, in Adams, Cumberland, and Franklin counties, is an extensive area which is placed with the Primal series. It is a continuation of the Blue Ridge of Maryland and Virginia. There are a few intrusive rocks, mostly of greenstone and trap. Some of the rocks are very crystalline, but none are regarded as belonging to the gneissic series. In this series are found limestones associated with iron ore.

LEEDS,[4] in 1870, states that on the Germantown Railroad, 3 miles from Philadelphia, in the micaceous schists are embedded huge bowlders of hard, compact, hornblende rock. They are supposed to be a

Primitive surface formation which was broken up before the deposition of the metamorphic rocks of undetermined age.

Frazer,[5] in 1876, describes several sections in York and Adams counties. Here are included hydromica slates and hydromica schists, chloritic rocks, quartzite, quartz slate, gneissoid mica schist, limestone, and chert. Several sections show an unconformable contact between the York limestone and the crystalline schists. The latter usually dip at a high angle.

Frazer,[6] in 1877, describes cross sections in the counties of York, Adams, Cumberland, and Franklin. In South Mountain the structure is found to be essentially the same as that given by Rogers, except that it also contains limestone. In one section is a thickness of more than 17,000 feet of quartzite and sandy shale and about 2,000 feet of chloritic slates. In another section the rocks observed are quartz conglomerate schist, jaspery quartzites, crystalline schists, and orthofelsites. The relations seem to show an unconformity between the older (Huronian?) orthofelsites and schists and the more recent (Cambrian?) sandstone, but they would seem additionally to imply that the alignment of the one system was the result of causes entirely different from and anterior to those that formed the other. In another section the rocks increase in felsitic character to the southeast and in conglomeratic schistose character to the northwest. It is concluded that the South Mountain chain is composed of two groups of rocks, the lower consisting of quartz conglomerates in which quartzite occurs; the upper felsitic in character, containing hydromica schists and chlorite schists. The felsite itself ranges from a sandy slate to a coarsely porphyritic rock.

Hunt,[7] in 1877, states that near Conshohocken is a belt of Laurentian gneiss, identical with that of the South and Welsh mountains, that separates the Philadelphia gneisses and mica schists, which are Montalban, from the Auroral limestone. The Laurentian gneiss is succeeded on the northeast by serpentines, chloritic schists, micaceous schists, and argillites, which are typical Huronian rocks. The intermediate position of the Huronian seems to show that it is below the Montalban. The Primal and Auroral are the Lower Taconic of Emmons. South of the Susquehanna, South Mountain rocks again appear and stretch southward to the Potomac. They here consist of Montalban and Huronian rocks. In the southern part of Pennsylvania are bedded petrosilex rocks, often jasper-like, which are associated with characteristic rocks of the Huronian series, to which they are all referred.

Prime,[8] in 1878, describes gneiss and mica schist in Lehigh County as Laurentian. A little west of Seller's quarry the Potsdam sandstone and Laurentian rocks are seen in contact. The dips of the two seem to be conformable, but this may be wrong, as the exposure is small and the gneiss apparently has a slight roll. The gneissic rock is here distinctly bedded.

Frazer,[9] in 1880, includes in the post-Eozoic series of Lancaster County calcareous argillites, nacreous slates, hydromica schists, Chikis quartzite, and chloritic series. In the Eozoic series is placed the mica schist and gneiss belt. Between this series and the previous one there is no certain evidence of unconformity, the transition from one rock to the other being gradual and the line between them difficult to define.

Frazer,[10] in 1880, states that the chloritic series pass into the Peach Bottom slates within a breadth of a few hundred yards, and equally abruptly into chlorites again, and finally into greenish chloritic quartzite, in all respects like those of the South Mountain. If the Peach Bottom slates are of Hudson River age, as supposed, a difficulty is here presented.

Hall (C. E.),[11] in 1881, describes Philadelphia County and the southern parts of Montgomery and Bucks. The schistose rocks are placed in the three belts as divided by Rogers, but there is an intermediate belt between the first and second belts of Rogers. The first belt is made up of gray schistose gneiss, composed of quartz, feldspar, and brown or black mica, with occasional garnets, interlaminated with occasional beds of black hornblendic slate and fine-grained sandy gneiss. The second belt is characterized by serpentine, soapstone, silvery micaceous garnetiferous schists, and light-colored thin-bedded sandy gneisses, with disseminated light-colored mica in minute flakes. The third belt is composed chiefly of quartz, feldspar, and hornblende. The beds are often massive, but usually have thin bands of mica or hornblende through them. They are syenitic and gneissic granites or granitic gneisses in which is found a peculiar variety of blue quartz. The prevailing northward dips of the schists and gneisses of the first and second belts do not hold for the third. The Primal sandstone (Potsdam), wherever it occurs, invariably rests upon the rocks of the third belt, and its sandstones and conglomerates are invariably composed of débris from this belt, and in it is found not a single flake of mica, quartz, or other material which can belong to the first or second belts. For considerable distances the Primal rocks are found between the third belt and the schists of the second belt. At the Schuylkill the rocks of the first and second belt rest upon and against the rocks forming the third belt. The third belt is regarded as Laurentian and the first and second belt are assigned a position above the Primal Potsdam sandstone and the Auroral limestone. In the midst of the roofing slates of Susquehanna River occur Hudson River fossils, and the first and second belts are referred to or above the Hudson River group, while the third belt is referred to the Laurentian.

Lesley,[12] in 1883, describes the continuation in the southern part of Northampton County of the Highlands of New Jersey. There are in this region four ranges. In the valleys are limestones, the stratification of which is visible everywhere but is much broken and crumpled. The stratification of the gneiss or syenite beds of the mountains is, on the contrary, rarely to be seen and can be judged only from topographical features. Dips are hard to find, owing to the general decomposition of the rock surfaces of the country, to the amount of débris on the surface, to the vegetation, and to the massive and homogeneous character of the beds where the true bedding plane has sometimes been made out by observing the parallel arrangement of the minerals. The South Mountain gneisses evidently belong to a different system from the Philadelphia belt and are comparable with the Laurentian system. Why they are not covered by Huronian or Cambrian rocks is not known. If, as supposed by those who do not accept the views of Hall, the rocks of the Philadelphia belt underlie the Potsdam and overlie the Philadelphia syenites, it is hard to see why these rocks do not appear between the Potsdam and the gneisses at South Mountain. The ridges, instead of being simple anticlines, are a series of anticlines and synclines. At Morgan Hill there is discordance between the dips of the Potsdam and the gneiss, showing apparent unconformity. The syenite rocks underlie the limestones, which may represent residual material that has not been removed by erosion. The crystalline character of these outlying ridges of limestone may be explained by the fact that the material has been buried 30,000 or 40,000 feet below the surface. At Chestnut Hill Gap, on the Delaware, the Potsdam sandstone is sometimes vitreous and over it are limestones changed into crystalline dolomites holding serpentines. At a contact with a dike of coarse granite near the south side of the gap the slates are changed into chlorite, mica slate, and hornblende slate, but in the coarser grits the original pebbles are seen.

Hall (C. E.),[13] in 1883, describes many localities of slates, gneisses, and granites in the South Mountain area.

D'Invilliers,[14] in 1883, states that the existence of anticlinal and synclinal folds in the South Mountain belt of Berks County is suggested by the alternate anticlinal and synclinal belts of limestone and slate, but it is not conclusively proved, for these formations belong to different systems of rocks, and no doubt lie unconformably upon the older mountain rocks. The South Mountain rocks are gneisses and granites, which are of two kinds—a distinctly stratified, thick-bedded, massive gneiss, and a stratified syenite in which hornblende is predominant. The eroded edges of the Potsdam sandstone run along the northern slope of the belt overlying the gneissoid rocks.

Hall (C. E.),[15] in 1885, places the syenites of Delaware County with the Laurentian. Overlying these are the micaceous and garnetiferous schists, these relations being well exposed at Chester Creek. The cleavage dip varies from 75° to 90°, but the true dips are nearly horizontal and undulating, which fact tends to reduce the hypothetical thickness of the crystalline rocks of southeastern Pennsylvania to a minimum. The serpentines occupy shallow synclinal basins and are the most recent of the metamorphosed rocks. East of Schuylkill River, outside of Delaware County, the schists rest upon the upturned edges of the Potsdam and limestones, proving the relative age conclusively. The serpentines, mica schists, and gneisses are regarded as more recent than the Hudson River group. In this schistose series one kind of rock gradually fades into the next succeeding kind, which renders a delineation almost impossible.

FRAZER,[16] in 1885, states that at Hendersons station, in the Philadelphia region, there is an unconformable contact of the limestone with the sandstone; and that in the section here there is a series of gentle folds rather than a monoclinal structure, as made out by Hall.

FRAZER,[17] in 1886, describes the Archean rocks of York County. The lowest members of the Archean series here found are the Huronian schists, which have a thickness of 14,400 feet. A somewhat arbitrary division is made between the Huronian and the next following age, the rocks of which are denominated Azoic schists or phyllites, as they can not be certainly assigned either to the Archean or to the Paleozoic. A belt of them is found on either side of the broad Huronian area of the crystalline schists.

RAND,[18] in 1889, describes a section of the crystalline rocks from the Triassic of Chester County, Pa., to the Cretaceous of New Jersey, passing through Philadelphia. The rocks are doubtfully referred to various horizons, running from the Laurentian to the Hudson River.

LESLEY,[19] in 1892, gives a summary sketch of the pre-Cambrian rocks of Pennsylvania, the facts being taken from the detailed State reports. The Highland belt of New Jersey and Pennsylvania; the Reading and Durham hills; areas in Chester, Bucks, Montgomery, and Delaware counties; and an area on Schuylkill River are placed in the Archean. All are regarded as sedimentary in origin, because of the presence of marble, apatite, and iron ore. The newer gneiss of the Philadelphia belt, the Azoic formations of York, Chester, and Lancaster counties, and the South Mountain rocks are not definitely referred to any system. The term Huronian must be used simply as a proper and private name for a series of rocks exposed along a part of the northern boundary of the United States. Should a similar series appear in some other region and be called Huronian on account of the resemblance, the name would have no value whatever, unless we should imagine that in a so-called Huronian age the whole surface of the planet was stuccoed with a certain formation and received successive coats of other kinds of rock in after ages. The most dissimilar series of formations are known to be of the same age. What is happening to-day has happened in all ages. Nothing could be more unlike than the deposits now forming along the various ocean shores and in different lakes and inland seas, yet they are all of one age. Even the deposits making in one and the same basin radically differ; as, for example, along the northern and southern sides of Lake Ontario and along the eastern and western sides of Lake Champlain. It would therefore seem a useless task to seek for the Huronian rocks far from their native range.

Bascom,[20] in 1896, describes and maps pre-Cambrian volcanic rocks of South Mountain, Pennsylvania. The volcanic rocks are both basic and acidic. The acidic rocks comprise quartz porphyries, devitrified rhyolites or aporhyolites, with accompanying pyroclastics, and sericite schists, the last being the metamorphosed forms of the quartz porphyries and aporhyolites. The basic rocks comprise melaphyres, augite porphyrites, slates, and pyroclastics. Lithologically the volcanic rocks resemble the Keweenawan copper-bearing rocks of Lake Superior.

There is not sufficient evidence to decide the comparative age of the basic and acidic rocks, but field observations in the Monterey district indicate that the acidic rocks are the older. The volcanics are overlain, with stratigraphical unconformity but with structural conformity, by sedimentary rocks of Lower Cambrian age. Both volcanics and sedimentaries have been subjected to strong dynamic action, whereby the igneous rocks have been cleaved and sheared and the sedimentary rocks thrust over them from the east.

Bascom,[21] in 1905, describes the geology of the Piedmont district of Pennsylvania. The summary on the following pages by Doctor Bascom practically covers the same ground and will not here be repeated.

See also summaries of work of Keith, Walcott, and others under Maryland, section 2.

SUMMARY OF PRESENT KNOWLEDGE.

EASTERN PIEDMONT BELT.[a]

The Piedmont district of Pennsylvania, forming, with a width of 65 miles, the southeast border of the State, constitutes an important part of the Atlantic Piedmont, and is in geology and physiography an epitome of the larger district. Geologically it is a complex of highly metamorphosed sedimentary and intrusive igneous materials largely concealed beneath a cover of Mesozoic sandstone and shale and of Cenozoic gravel, clay, marl, and sand. This cover conceals

[a] The summary for the eastern Piedmont belt has been prepared for this bulletin by Dr. Florence Bascom.

the crystallines in the central portion of the district, leaving them exposed in belts on the southeast and northwest borders.

The more easterly of these two belts, with an extension on the Maryland-Pennsylvania line of 72 miles, contracts to the northeast, and north of Trenton disappears altogether under the cover of later deposits. This belt contains the full series of formations found elsewhere in the Pennsylvania Piedmont. The series has been subjected to greater metamorphism than is the case in the westerly belt, due both to intense folding and to the injection of great masses of acidic and basic igneous material.

SEDIMENTARY ROCKS.

The sedimentary series is as follows:

Ordovician: Octoraro schist.
Cambro-Ordovician: Shenandoah limestone.
Cambrian: Chickies quartzite.
Pre-Cambrian {Wissahickon mica gneiss. / Baltimore gneiss.}

Baltimore gneiss.—This formation includes primarily a medium-grained granite gneiss in which hornblende is the chief ferromagnesian constituent, and subordinately a medium-grained arkose gneiss in which biotite is the chief ferromagnesian constituent. The granite gneiss has a more considerable distribution than the arkose gneiss and presumably represents the parent rock from which the arkose gneiss was derived. The mica of the arkose gneiss occurs in minute plates and is never developed in such dimensions or to such excess as to give a schistose character to the formation, which is normally characterized by a pronounced gneissic banding, often fine and closely plicated. The rock may further show a pseudoporphyritic texture, due to an original conglomeratic character. Graphite is sometimes present, disseminated in minute scales or occurring in such abundance as to be of economic importance. The presence of this mineral, the absence of such microscopic pressure effects as dynamic force produces in an igneous formation, the rounded apatites, and the sorting of mineral constituents are microscopic evidences of a sedimentary origin, which are supported by field evidence.

Buck Ridge, a highland occupying the central portion of the belt, is composed of a complex of the Baltimore gneiss and a gabbro by which it is thoroughly injected and which gives the gneiss a massive and granitic aspect along contacts. Where Schuylkill River cuts through Buck Ridge the Baltimore gneiss is exposed in an anticline. On the southeast the Wissahickon mica gneiss has been brought adjacent to it, presumably by a thrust fault, and on the northwest it is flanked in normal succession by a Cambrian quartzite.

The Baltimore gneiss is therefore held to be pre-Cambrian in age and is correlated with the pre-Cambrian Stamford gneiss of New England, with the Fordham gneiss of New York, the Baltimore gneiss of Maryland, and the Carolina gneiss of Virginia. While the pre-Cambrian gneiss of Pennsylvania is not stratigraphically continuous at the surface with the Baltimore gneiss of Maryland, the like lithologic character, stratigraphic relations, and the proximity of the formations have found recognition in a common name. The Baltimore gneiss embraces H. D. Rogers's Primal Lower Slate and part of his third gneiss belt ("Hypozoic"); the major part of this gneiss belt is gabbro. Both the gabbro and the Baltimore gneiss are included under the term "Laurentian gneiss" by the Second Geological Survey of Pennsylvania.

Wissahickon mica gneiss.—This formation, while showing great local variation, may be described as a medium-grained quartz-feldspar rock characterized by an excess of biotite. The gneissic structure is due to beds of varying composition, quartzose or feldspathic beds alternating with excessively micaceous layers. Hornblende, garnets, tourmaline, andalusite, sillimanite, and zoisite are accessory metamorphic minerals.

The mica gneiss, with its associated igneous intrusives, extends from New Jersey to Maryland and from Buck Ridge, south of Chester Valley, eastward to Delaware River, where it passes under a cover of Cenozoic materials. It is well exposed in the gorge of Wissahickon Creek, from which the formation takes its name. The beds show crumpling and anticlinal and synclinal folding. The thickness is probably between 1,000 and 2,000 feet.

The age of the Wissahickon mica gneiss is still in question; its determination rests wholly upon evidence afforded by the stratigraphic relations which the mica gneiss sustains, or appears to sustain, to fossil-bearing sediments. The formation contains within itself no clue to its age. While the Wissahickon mica gneiss apparently overlies with anticlinal structure presumably Cambro-Ordovician limestone, that the actual structure is one of overturned or in some cases fan-shaped synclines, bringing the mica gneiss below the limestone, is shown to be presumptively the case by the following field evidence: The separation of the Wissahickon gneiss from adjacent known Ordovician mica schist; the occurrence in some cases between the gneiss and the limestone of tourmaline-bearing quartzite; the occurrence within the gneiss areas of lenses of similar quartzite, and of mica schist similar to that which is interbedded with recognized Cambrian quartzite; and, finally, unconformity between the Wissahickon gneiss and recognized Paleozoics. This evidence is far from being conclusive, and present knowledge only establishes a presumption that the Wissahickon mica gneiss is probably of pre-Cambrian age and that it carries lens-shaped deposits of Cambrian mica schist and Cambrian quartzite; the Cambro-Ordovician limestone resting, by means of overlap, in some places directly upon the pre-Cambrian mica gneiss surface and in others upon an inconsiderable thickness of Cambrian material.

The whole series, pre-Cambrian mica gneiss, Cambrian mica schist and quartzite, and Cambro-Ordovician limestone, has been folded into fan-shaped anticlines and synclines, in the troughs of which the limestone has been preserved from erosion and has been thrust, by means of a fault hading gently southeast, upon the Baltimore gneiss and the Paleozoic series. In the southern portion of the belt Ordovician mica schist is thus brought adjacent to the Wissahickon mica gneiss and is with very great difficulty separated from it. To the north, first Baltimore gneiss and then Cambrian quartzite are brought in contact with the Wissahickon mica gneiss. The Wissahickon mica gneiss is to be correlated with the mica gneiss of Maryland. With this formation the mica gneiss of Pennsylvania is stratigraphically continuous. The Wissahickon mica gneiss, together with the intrusive granite and gabbro, comprises Rogers's first and second gneiss belts ("Hypozoic"). It embraces the "Chestnut Hill," "Manayunk," and "Philadelphia" mica schists and gneisses, mapped as pre-Cambrian by the Second Geological Survey of Pennsylvania.

IGNEOUS ROCKS.

The igneous rocks of the Piedmont belt are exclusively intrusive in character and embrace both acidic and basic types. The oldest intrusive is a granite batholith, characteristically porphyritic and gneissoid. The basic intrusives are chonoliths and dikes of a gabbroitic type—gabbro, hypersthene gabbro, norite, pyroxenite, peridotite, metapyroxenite and metaperidotite or serpentine and steatite, chlorite schists, and associated decomposition products.

These igneous bodies occur abundantly in the Wissahickon mica gneiss and the Baltimore gneiss. While isolated islands of hornblende gabbro and of serpentine occur in Ordovician material, the igneous material is otherwise confined to the gneisses, and is presumptively pre-Cambrian in age. Similar intrusives are found in the Atlantic belt of crystallines from Virginia to New York.

Dikes of Triassic diabase of a uniform petrographic character are found in the Piedmont district. Two species are present—an ophito-augite bandose and an ophiti-augite auvergnose.

HIGHLAND BELT.[a]

The geology of the Highland belt, worked out for New Jersey, doubtless extends southwest into the Pennsylvania Highland belt. No recent detailed mapping has been done here. The rocks are described by Lesley as a complex of syenite, granite, granulite, hornblende schist, mica schist, magnetic iron ore, and hornblende gneiss, lacking the crystalline limestone beds characteristic of the New Jersey Highlands.

SOUTH MOUNTAIN OF PENNSYLVANIA.[a]

As shown by the work of Walcott, Williams, Keith, and Bascom, the oldest rocks in South Mountain of Pennsylvania are felsites and basalts, the former being predominant. Both of these vary from compact to amygdaloidal, and are accompanied by tuffs and breccias. The volcanics have been extensively transformed into slates and schists by dynamic action. These are unconformably overlain by quartzite conglomerates and sandstones, or by shales, which bear the *Olenellus* fauna.

It therefore follows that the volcanic rocks of South Mountain are pre-Cambrian, but as yet no evidence is available to give them a more definite place than this.

SECTION 2. MARYLAND AND ADJACENT PORTIONS OF VIRGINIA AND PENNSYLVANIA.

SUMMARY OF LITERATURE.

Ducatel and Alexander,[22] in 1834, describe the Primary rocks as one of the chief divisions. These include the following formations: Granite, gneiss, limestone, and serpentine.

Aikin,[23] in 1834, states that granite and Primitive schists are intermingled in every possible manner in the region west of Baltimore, the dips being with a good deal of regularity toward the southeast. Succeeding the Primitive rocks are Transition slates, sandstones, limestones, and graywackes interstratified with Transition limestones.

Ducatel,[24] in 1839, states that the limestones of Harford and Baltimore counties occur in the valleys. In the northwestern part of these counties the rocks are argillites, which pass into talcose slates, and these are succeeded by granitic aggregates in which hornblende is the prevailing rock.

Tyson,[25] in 1860, classifies the rocks of Maryland into those of igneous and aqueous origin. In the former are granite, syenite, massive quartzite, porphyry, amygdaloid, trap (including hornblende rock or amphibolite), and serpentine. The rocks of aqueous origin include

[a] By the authors.

chemical deposits, among which are limestone and dolomite; mechanical deposits, among which are sandstone, conglomerate, breccia, clay slate, shale, and clay; and metamorphic rocks, among which are gneiss, mica slate, hornblende slate, talc slate, quartzite, granular limestone, and dolomite. The rocks of igneous origin are defined as those which give no evidence of stratification. These are found in the area about Baltimore, mingled with the sedimentary rocks. In the limestones in many places the stratification has been obliterated. Gneiss is the most largely developed of the rocks in the central part of the State. While there is usually ample evidence of stratification in gneiss, in some localities it has been so much altered by the joint action of heat and intrusive forces as to have nearly obliterated its stratification planes and cause it to resemble granite. The four lowest formations of Maryland are eruptive; the fifth formation is composed of gneiss, mica slate, and hornblende slate, which includes the intrusive rocks of the first four formations and a portion of the limestone. These rocks occur as a belt in Cecil, Harford, Baltimore, Howard, and Montgomery counties, and are bounded on the northwest by—or, more correctly speaking, pass by insensible shades of difference into—the talcose slates. Near the southwestern limit the prevailing rock is gneiss, which is interlaminated with hornblende slate. Toward the northwest mica slate increases in quantity, and finally passes into talc slate. The metamorphic limestones are found in two belts—(1) the gneisses and mica slates, and (2) the talcose slates.

Williams,[26] in 1886, describes the gabbros and associated hornblendic rocks of Maryland. These are all found to be of igneous origin and the schistose hornblendic rocks the result of metamorphism.

Williams,[27] in 1891, describes the structure of the Piedmont Plateau in Maryland. The western part is a semicrystalline area consisting of phyllites, sandstones, marbles, and but few eruptive rocks. The eastern area is completely crystalline. The sedimentary rocks include biotite gneiss, biotite-muscovite gneiss, muscovite gneiss, mica schist, quartz schist, conglomeratic quartz schist, and dolomitic marble. Within this area are very numerous eruptive rocks, including granites, gneisses, gabbros, diorites, and basic rocks, such as pyroxenite, lherzolite, etc. Two sections are described in detail. In the semicrystalline rocks a cleavage is developed which much obscures the bedding, and the succession may be repeated many times by folds and faults. Between the semicrystalline and completely crystalline rocks there is a somewhat abrupt passage. The structure of the western area can be accounted for by a single period of folding, while the eastern area, as shown by its implicated structure, must have been wrenched, folded, and faulted at different times. It is concluded that the eastern area is composed of rocks far more ancient than the western, which extend under the latter, forming the floor upon which they were deposited. This hypothesis accounts for the difference in crystalline character between the rocks of the two areas, for the abruptness of their contact, and, since both series have been subjected to a folding together, for their apparent conformity along their contact. As to the age of the rocks, it is probable that the Paleozoic should include all the semicrystalline schists, while the holocrystalline rocks east of them would be assigned to the Algonkian or Archean.

KEYES,[27] in 1891, gives as a supplement to the preceding a section across the Piedmont Plateau of Maryland. In the Frederick limestone of the western semicrystalline rocks are fossils of several types characteristic of the Trenton, and the entire series of limestones and shales probably represent the Chazy, Trenton, and Hudson River formations. East of the western semicrystalline rocks are contorted gneisses, with general westerly dips, which are cut by basic and acidic rocks and which are believed to have been originally granitic, but through the agency of enormous orographic pressure have been squeezed into their present gneissic condition, as shown by the mechanical deformations through which the grains have gone.

KEITH,[28] in 1892, summarizes the geologic structure of the Blue Ridge in Maryland and Virginia. Considered in a general way, the region is a broad anticline and successively younger rocks appear east and west from the nucleus of igneous rocks. This arch is crumpled into several synclines and broken by faults that follow the mountain lines rather closely. The igneous rocks near the nucleus are the only pre-Cambrian rocks present. The physical history of the area is, in brief:

Surface flow of quartz porphyry, followed after short interval by surface flow of diabase. Injection of granite into the diabase, presumably passing through the quartz porphyry. Dynamic action and production of schistosity in diabase.

Erosion.

Submergence and deposition of Paleozoic strata. Dynamic action with folding, cleavage, and elevation.

Erosion.

Submergence and Juratrias deposition.

WILLIAMS,[29] in 1892, describes the volcanic rocks of South Mountain and emphasizes their volcanic character. Most of these, with the exception of a few of the most massive greenstones, have hitherto been regarded as of sedimentary origin, because of their accompanying accumulation of tuff beds and breccias, and the fact that they are generally cleaved parallel to the great structure planes of the mountain. The rocks are principally rhyolites and basalts.

WALCOTT,[30] in 1892, determines the Cambrian age of the quartzite bordering on the igneous rocks of South Mountain and its southern extension, the Blue Ridge. The underlying igneous rocks are therefore pre-Cambrian.

DARTON,[31] in 1892, finds Ordovician fossils in the crystalline slates and schists of the Piedmont Plain of Virginia, these rocks having been previously regarded as Huronian.

WILLIAMS and CLARK,[32] in 1893, describe and map the geology and physical features of Maryland. The pre-Cambrian rocks, described by Williams, form the eastern or holocrystalline division of the Piedmont Plateau region of Maryland, crossing the State in a general southwest direction from the southeast corner of Pennsylvania and the north end of Delaware. These rocks are but a part of the great crystalline plateau which extends from New York to Alabama along the eastern base of the Appalachians. Toward the east the pre-Cambrian rocks of Maryland plunge under Coastal Plain deposits and toward the west they form the floor to support the Paleozoic strata of the Appalachians, reappearing in the granitic and volcanic rocks of South Mountain of Pennsylvania. The holocrystalline rocks are divisible into six types, three of which—gabbro, peridotite or pyroxenite, and granite—are of undoubted eruptive origin, and three of which—gneiss, marble, and quartz schist—while showing no certain evidence of clastic structure, are believed to be sedimentary. The prevailing rock is gneiss, closely associated with marbles and quartz schists, forming an intricate complex. The complex shows evidence of great dynamic action, the rocks having been almost completely recrystallized. The eruptive rocks are all younger than the gneisses. The gabbro is the oldest, followed by the peridotite or pyroxenite, and the youngest is the granite. The granites are as a rule medium-grained biotite granites, but they frequently take the form of pegmatite.

KEYES,[33] in 1893, holds that the granites of Maryland are eruptive, since these rocks indiscriminately cut across the other igneous rocks of the region, as well as the gneiss; because they hold inclusions of the other rocks of the region; because the rocks cut show contact phenomena, and because a microscopical examination shows that they possess all the characters of rocks cooled from fusion.

GRIMSLEY,[34] in 1894, describes and maps the rocks of a part of Cecil County in northwestern Maryland. The rocks are granite, diorite, and staurolitic mica schist. The staurolitic mica schist is regarded as a sedimentary rock. In this the granite gneiss is intrusive, as shown by the fact that branching dikes and apophyses penetrate the adjoining schists and slates, producing pronounced contact effects upon them. The diorite occurs in dikes in the granite.

DARTON,[35] in 1894, maps and describes the geology of the Fredericksburg quadrangle, in Virginia and Maryland. In the northwestern and western parts are granite, gneiss, and schist, and a belt of rock called the Quantico slate, which locally appears to grade into siliceous mica schist or gneiss. It is about three-quarters of a mile in width, and strikes northeast-southwest. The granite, gneiss, and schist are regarded as pre-Cambrian. The slates resemble the roofing slates on James River, which carry Lower Silurian fossils.

KEITH,[36] in 1894, gives the geology of the Catoctin belt. The pre-Cambrian rocks constituting the Blue Ridge core are all of igneous origin and are assigned to the Algonkian. They include quartz porphyry and andesite, Catoctin schist, and granite. A detailed lithological description is given of each of these rocks and of their alterations. The Catoctin schist and the granite are separated by areas in which the two are intimately intermingled. The Catoctin schist is an altered diabase, and the diabase is believed to be separable into two flows with a time gap between them. An evidence of this is a discordance of structure. The order of the events was probably as follows: (1) Diabase extrusion, (2) granite intrusion, (3) erosion interval, (4) quartz porphyry and andesite flows, (5) erosion interval (?), (6) diabase flow, and (7) erosion interval. The different lavas have been folded and faulted, and secondary structures have developed within them. Metamorphism was most extensive in the diabase, which has become a well-developed schist. The quartz porphyry is the least altered.

MERRILL,[37] in 1895, describes the disintegration of the granite rocks in the District of Columbia, and finds from chemical analysis, calculated on a water-free basis, that they are very similar to those of the original rocks, and therefore that the rocks are as much disintegrated as decomposed. The chief chemical change is hydration.

KEYES,[38] in 1895, gives a detailed petrographical description of the Maryland granites. For reasons the same as given by Williams they are regarded as eruptive, and many of the gneisses are shown to be dynamically metamorphosed granites.

WILLIAMS,[39] in 1895, considers the general relations of the granitic rocks in the middle Atlantic Piedmont Plateau and maps the same. The criteria by which ancient plutonic rocks in highly metamorphosed terranes may be recognized comprise radiating dikes, inclusions of fragments, contact zones, chemical composition, and petrographical structure. On these criteria it is concluded that most of the granitic rocks of Maryland are igneous, although many of them are changed to granite gneiss, and of certain of these gneisses it can not be asserted whether they are of aqueous or of igneous origin. South of Laurel, in the large area from Triadelphia southward to Brookville, at Murdoch Mill west of Washington, south of Falls Church in Fairfax County, Va., and at Cabin John Bridge on Potomac River there are gradations between granitic rocks and diorites or gabbros. In the Maryland rocks pegmatites are abundant. Some of these are, as indicated by their association with quartz veins and by parallel banding, water segregations. The majority, however, are igneous, as is shown by all of the phenomena of intrusive rocks.

CLARK,[40] in 1897, describes the geology and physical features of Maryland. This account is essentially the same as that published by Williams and Clark in 1893, already summarized (p. 667). Here, however, the crystalline rocks are classed as Archean and Algonkian, both of which are included under the general term Archean. The statement is made that there is no positive evidence that rocks of the earliest portion of Archean time (meaning Archean proper) are represented in Maryland, although a part of the gneiss complex may represent it. The Algonkian period, however, is represented by many varieties of rock. The rapidity with which the crystalline rocks furnished sediments for the overlying formations points to their high elevation in Archean time.

In the western division of the Piedmont Plateau region of Maryland, Algonkian rocks are infolded with the Paleozoic deposits of Montgomery, Frederick, and Carroll counties. They consist of a single type resembling the metamorphosed basic volcanic rocks (Catoctin schist) of the Blue Ridge district.

CLARK,[41] in 1897, describes the physical features and geology of Maryland, and gives a sketch of the development of knowledge concerning them. The description of pre-Cambrian geology is essentially the same as that given by Clark in the preliminary publication of this part of the volume (noticed above), and this in turn is but slightly different from the account given by Williams and Clark in 1893 (noticed on p. 667). However, a few minor changes may be noted. The crystalline rocks of the Piedmont Plateau region, instead of being divided into six types as before, are divided into seven types, diorite being added to the list. Rocks of the Archean period are placed in the table of formations as doubtfully present.

KEITH,[42] in 1901, describes and maps the geology of the Piedmont Plateau of the Washington district. Igneous rocks of Archean age are mapped under the following divisions: Biotite granite, soapstone and serpentine (altering from peridotite and pyroxenite), gabbro, metagabbro, diorite and metadiorite, granite (including gneissoid granite and schistose granite), and Carolina gneiss (including mica gneiss, mica schist, and small bodies of granite, schistose granite, and diorite). In age these rocks rank in the order named, the Carolina gneiss being the oldest. Also the relative areas of the groups nearly correspond with their ages.

MATHEWS,[43] in 1904, discusses the structure of the Piedmont Plateau. The Baltimore gneiss (Williams's biotite gneiss in part) is correlated with the Fordham gneiss of New York, the Baltimore gneiss of Philadelphia, and the Carolina gneiss (in part) of the

Washington area, all of which are referred to the pre-Cambrian. He concludes that:

1. The older rocks of the Piedmont consist of both sedimentary and igneous types which since their formation have been more or less metamorphosed.

2. The metamorphosed sediments include banded micaceous and hornblende gneisses of pre-Cambrian age; a more or less intermittent, thin-bedded, generally tourmaline-bearing quartzite of Cambrian age; and intermittent dolomitic marble or magnesian limestone of Cambro-Ordovician age; and a series of mica schists and the gneisses of Ordovician age. Above these occur a somewhat intermittent, poorly developed, quartzitic conglomerate and the Peach Bottom slates.

3. The igneous rocks consist of an immense gabbro mass, intruded by numerous large bodies of granite and metarhyolite, and accompanied by numerous more basic serpentinized bodies. These various masses represent stages in a single extended period of igneous activity.

4. The time when this activity took place was later than early Silurian and earlier than late Carboniferous, probably in the early part of this interval.

5. The chief structural features of the region are the metamorphism and contant schistosity and the broader folding of the different rocks.

6. The metamorphism of the rocks, especially of the banded gneisses, probably commenced prior to the intrusion of the gabbro and granite, and was accentuated by them in the eastern portion of the plateau.

7. The folding of the region is of the Appalachian type, the rocks occurring in several long, more or less parallel folds, with few faults and but occasional overturned folds.

8. The eastern and western areas are probably of the same age, differences in metamorphism being due to the large bodies of deep-seated intrusives on the east and the smaller bodies of surface volcanics on the west.

9. The sequence found in Maryland may be recognized from Washington to Trenton and in the region north of New York.

MATHEWS,[44] in 1905, concludes that the four formations recognized by Bascom in the Philadelphia area may be traced across Maryland and that they probably constitute the bulk of the rocks forming the Piedmont of Virginia which have heretofore been mapped as a unit. Within the Maryland Piedmont, so far as studied in detail, there are no means of locating accurately the position in the stratigraphic column of the four formations—Baltimore gneiss, Setters quartzite, Cockeysville marble, and Wissahickon schists—but on either end of a continuous extension of these formations we have a sequence into sedimentary rocks of known horizon. On the east Bascom has considered that the Baltimore gneiss is pre-Cambrian, the quartzite Cambrian, the limestone Cambro-Ordovician, and the Wissahickon Ordovician. On the west the phyllites are apparently in the same relation to the known Cambrian and Cambro-Silurian deposits, although in this area the geological mapping has not been conducted in detail on account of the lack of satisfactory topographic maps. The conclusion from the facts at hand would therefore seem to warrant the following correlation:

Correlation of Piedmont of Maryland and Pennsylvania.

	Maryland Piedmont.			Pennsylvania Piedmont.	
	Western.	Central.	Eastern.	Southern.	Eastern.
Ordovician	Massanutten sandstone. Martinsburg shale.	Phyllite and Wissahickon schists.	Peachbottom slate. Cardiff quartzite. Wissahickon formation.	Wissahickon formation.	Hudson River.
Cambro-Ordovician.	Shenandoah limestone.	Cockeysville marble.	....	Chester Valley.	Cambro-Silurian.
Cambrian	Antietam sandstone. Harpers shale.. Weverton sandstone. Loudon formation.	Setters quartzite with argillaceous upper member.	....	Chickies quartzite.	Cambrian.
Pre-Cambrian.	Granites, schists, etc.	Baltimore gneiss.	Baltimore gneiss.	Baltimore gneiss.	Pre-Cambrian.

Opposed to this conclusion is the fact that directly on the strike of the Wissahickon schist is a series of more quartzose and compact metamorphosed sediments which have been regarded by Keith in his discussion of the geology of the Washington quadrangle as Carolina gneiss, which, as defined by him, is pre-Cambrian. The grounds for assigning such an age to rocks of this region involve the areal work of Keith in the region to the north and west of Washington, which has not yet been published on account of the lack of a proper topographic base.

The Baltimore gneiss, the only pre-Cambrian formation, occurs in several well-defined areas in the eastern portion of the Piedmont between Susquehanna and Potomac rivers. The easternmost of these Baltimore gneiss occurrences is within the area of Cecil County, east of Susquehanna River, studied by Bascom, and extends from this point southward, widening to an area of 5 miles or more in breadth where it is overlain by Coastal Plain deposits. This formation is limited on either side by igneous rocks. An outlier, a mile or less in width, extending for several miles southward from Susquehanna River probably represents a detached portion of the larger mass lying a little to the south.

The second occurrence of Baltimore gneiss is found in an anticlinal dome 15 miles long and 5 miles broad lying on either side of the Northern Central Railroad 10 miles south of the Mason and Dixon line and 20 miles north of Baltimore.

Three smaller areas occur in the vicinity of Baltimore; two of them are portions of anticlinal domes which are either completely inclosed by overlying sediments or are cut off by faults and igneous rocks, while the third, underlying the northwestern part of Baltimore city, is entirely surrounded by gabbro and other igneous masses and is overlain in great measure by the Coastal Plain deposits.

Between Baltimore and Washington, along the boundary line between Montgomery and Prince George counties, occurs another area of Baltimore gneiss which up to the present time has not been fully investigated.

The rocks in each of these areas consist of highly crystalline gneisses composed of quartz, feldspar, and mica with accessory minerals which are so distributed as to produce well-marked gray banded gneisses, the individual bands of which vary from a fraction of an inch upward, the average breadth, however, being small. Some of these beds are highly quartzose, resembling a micaceous quartzite; others are rich in biotite or hornblende, producing dark schists which in a hand specimen are indistinguishable from metamorphosed igneous masses. Within the areas of Baltimore gneiss are numerous small bodies of metamorphosed granites and more basic igneous rocks which have been intruded into the gneiss and subsequently metamorphosed until they are practically indistinguishable from it. The differences in character can now and then be recognized, but it has not been found possible to carry the mapping of these small igneous intrusions from one exposure to another, and many of them are so small that they could not be represented on maps of the scale employed.

The structural character of the Piedmont from Trenton southward to southern Virginia is similar throughout to the Appalachian structure of the less metamorphosed Paleozoics to the west. That is, one may recognize within the Piedmont a series of long and narrow folds and arches trending parallel to the trend of the Appalachians. An exception to this rule is noticeable in the central Maryland area, which lies toward the center of a local curve in the Appalachian structure, where the structural forms are more nearly circular than they generally are in the Appalachians.

Clark and Mathews,[44a] in 1906, give a general account of the geology of Maryland that is essentially similar, in regard to the pre-Cambrian, to the articles by Mathews covered by the two preceding summaries. The sedimentary part of the Baltimore gneiss is doubtfully referred to the Algonkian. The igneous rocks are grouped under the heading "Paleozoic-Archean."

SECTION 3. THE VIRGINIAS.

SUMMARY OF LITERATURE.

CORNELIUS,[45] in 1818, finds west of the Secondary formations ranges of granites, schists, and other Primitive rocks. The Blue Ridge is the dividing line between the granite and the limestone country to the west.

ROGERS (W. B.),[46] in 1840, describes the southern district east of the Blue Ridge as occupied mostly by rocks of very ancient date, most of them believed to be Primary. A part of them are in irregular masses, and others have regular stratification, but all are alike considered of metamorphic origin. Aside from these there occur igneous rocks. The more important metamorphic rocks are granite, syenite, gneiss, mica slate, talc slate, argillaceous slate, pseudo gneiss or gneissic sandstone, soapstone rocks, micaceous and talcose limestones, and marbles. By pseudo gneiss or gneissoid sandstone is meant rocks which resemble the truly crystalline rocks but which plainly betray their sedimentary origin by the rounded character of the quartz and other constituents. The igneous rocks cut the shales and sandstones of the Middle Secondary.

ROGERS (W. B.),[47] in 1841, gives the geological occurrences of the Primary and metamorphic rocks. In these, beds of limestone are included at various points. Quartz slate and quartzite are found in the Bull Run Mountains and other localities.

FONTAINE,[48] in 1875, describes several sections of crystalline rocks which are regarded as pre-Silurian. Among them are argillite, greenstone, and syenite. At a tunnel the contact of the Silurian with the argillite is beautifully exposed, and the great contrast of the two systems is well shown.

FONTAINE,[49] in 1875, describes the central part of the Blue Ridge as consisting of coarse granites and gneisses of Laurentian age. Along the eastern slope of the syenite is a formation of argillites which is covered by a series of mica slates, schists, and gneisses. The axis is occupied by talcose limestones, quartzites, mica slates, and hydromica slates which closely resemble those in Berkshire County, Mass. In this belt are probably two systems, one older than the Primordial, and the other metamorphosed Silurian. The unconformity which exists between the syenite and the argillite apparently shows the latter to be Huronian, although its age is not positively determined.

CAMPBELL (J. L.),[50] in 1879, states that the Archean rocks of the Blue Ridge are granite and syenite. They underlie the stratified rocks of the region, but are probably more recent than they, being thrown upward through them. The bedded rocks resting upon the syenite are much metamorphosed and gneissoid in character. These are followed by a bed of conglomeratic quartzite and slates, upon which lie unconformably the Primordial rocks.

Campbell (J. L.),[51] in 1880, describes the metamorphic Archean rocks along James River and the Kanawha Canal as including limestones, schists, and quartzites.

Campbell (J. L.),[52] in 1880, describes the Archean rocks at James River Gap as consisting of granulite and syenite, upon which rest much metamorphosed beds of conglomeratic quartzite, and over these slates. These Archean rocks are unconformably below the Primordial rocks, which contain fragments of slate and crystals of feldspar, epidote, etc., more or less waterworn and cemented together. The slates were metamorphosed before they were deposited in the Primordial strata. The syenite and granulite are eruptive rocks which have been thrown up since the deposition of the Primordial, as is indicated by the fact that the stratified rocks dip at a high angle away from the igneous masses, and also by the influence the heat of the igneous rocks has exerted upon the overlying slates and sandstones. Higher in the series traces are found of metamorphic changes. The syenite and granulite are supposed to be the result of aqueo-igneous fusion and to represent material which is really older than the stratified rocks.

Fontaine,[53] in 1883, describes the Blue Ridge between Turks Gap and Balcony Falls as consisting of Laurentian, Huronian, and Primordial rocks. The first is mostly gneiss; the second, mostly hornblendic, micaceous, and argillaceous schists; and in the Primordial is found *Scolithus*.

Rogers (W. B.),[54] in 1884, states that the Blue Ridge is a continuation of the Green Mountains of Vermont, the Highlands of New York and New Jersey, and the South Mountain of Pennsylvania, and, continued southward, becomes the Smoky or Unaka Mountains of Tennessee. The rocks consist for the most part of the older metamorphic strata, including gneiss and micaceous, chloritic, talcose, and argillaceous schists, together with masses referable to the earliest Appalachian formations, sometimes in a highly altered condition. Innumerable dikes and veins of all dimensions, consisting of a vast variety of igneous materials, penetrate this belt, disturbing and altering its strata in a remarkable degree. Southern dips are prevalent throughout the whole of the region. This is particularly the case in the southeastern or most disturbed side of the belt, but on the northwestern side the reverse dips are more common. In many cases the ordinary anticlinal and synclinal structures are regarded as overturned in a northwest direction, which makes the two sides of the fold approximately parallel, and when this is not the case gives the northwestern side a deeper dip than the southeastern. In many of the sections the unconformity between the Cambrian and the crystalline metamorphic rocks is unmistakable, the lower members of the former being seen to rest on the slope of the ridge, with northwest undulating dips on the edges of the 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 part of the mountain. But even in those instances it is not difficult to discern the true relations of the strata. Examples of the phenomena are the sections exposed at Vestals, Gregorys, Snickers, and Manassas gaps, and Jeremies Run, in the northern part of the Blue Ridge; and at Dry Run, Turks, Tye River, Whites, James River, Point Lookout, Fox Creek, and White-top Mountain gaps, in the middle and southwestern prolongation of the chain.

Campbell (J. L. and H. D.),[55] in 1884, conclude from an examination of the Snowdon quarries that the core of the Blue Ridge is an igneous mass belonging to the Archean, and that upon its northwestern slope are unconformable beds of slates, sandstones, and conglomerates which are Potsdam or Cambrian. They are in a highly metamorphosed condition, and were regarded by Rogers as Huronian, and by the authors as pre-Cambrian, but the discovery of fossils in them has definitely determined their age. The slaty cleavage of the quarries sometimes corresponds with the planes of original bedding or stratification, but more frequently is more or less oblique to the strata.

Geiger and Keith,[56] in 1891, in discussing the structure of the district about Harpers Ferry, state that between the Cambro-Silurian shale and the granite schist there is an unconformity of the ordinary type of deposition.

Darton,[57] in 1892, finds Ordovician fossils in the crystalline slates and schists of the Piedmont Plain of Virginia, these rocks having been previously regarded as Huronian.

Darton,[35] in 1894, maps and describes the geology of the Fredericksburg quadrangle, in Virginia and Maryland. See summary in section 2, Maryland, etc., pages 667–668.

Watson,[58] in 1902, describes the copper-bearing rocks of the Virgilina copper district of Virginia and North Carolina and shows the adjacent rocks to be pre-Cambrian metamorphosed andesite associated with corresponding volcanic clastics. All are collectively referred to as greenstones, and are thought to be similar to greenstones described as occurring along the Atlantic coast region from eastern Canada to Georgia and from Alabama to the Lake Superior region.

See summaries of work of Walcott, Keith, and others under Maryland, section 2 of this chapter.

SECTION 4. DELAWARE.

SUMMARY OF LITERATURE.

Booth,[59] in 1841, includes among the Primary rocks gneiss, feldspathic rocks, limestones, serpentine, and granite, the first comprising about three-quarters of the area. This region is, without question, stratified. The average bearing of the rocks is N. 47° E., and the average dip 70° NW., but occasionally bearings are found which differ widely from this, as well as vertical dips. The trap rocks are in dip and strike comformable with the gneiss and grade into it. The limestone is a coarse to fine grained crystalline marble, interstratified with the gneiss. The serpentine and surrounding rocks are cut by numerous veins of granite. The greater part of the trappean formation possesses a clearly stratified structure and grades by transition into the gneiss, but the hornblendic and coarse feldspathic veins do not. The variation in the strike and dip of the gneiss is regarded as due to the granitic veins or to the serpentine.

Chester,[60] in 1885, places in the Laurentian the hornblendic rocks along the line of the Pennsylvania Railroad and the area to the east of West Chester. The rock is a dark hornblendic gneiss or amphibolitic schist, with which is associated a dioritic or syenitic granite of the Pennsylvania Survey. The two rocks grade into each other, and probably form varieties of the same eruptive series. North of the Laurentian gneisses, and resting upon them, is a series of mica schists and granitic gneisses, with which are associated bedded granites, serpentines, and hornblende rocks which have been referred to the Montalban, or, with the Laurentian, have been called Azoic. These do not form two successive formations, for, while the former is either Laurentian or Huronian, the latter must be placed above the Trenton, and possibly above the Hudson River slates. The granite of the State is in intrusive beds and in beds which are no more than highly metamorphosed granitic gneiss or mica schist, the two latter grading into each other. Crystalline limestones are found at Pleasant Hill, Hockessin, and near Centerville. Serpentine is found northeast of Wilmington as a dike, running with the micaceous schist. Vitreous quartz and quartzite occur as thin or massive seams interstratified with the micaceous rocks. The quartzite of the northeast corner of the State, underlying limestone, is probably of Potsdam age. The strikes and dips of the crystalline rocks are very variable, and this variation is often due to the disturbing action of granitic intrusions. The Laurentian is an extension of the third belt of Rogers. The limestones are younger than the Potsdam quartzites, and are regarded as Calciferous; the mica schists and gneisses certainly overlie the limestones, and the latter therefore begin somewhere in the Silurian, and possibly mount as high as the Devonian.

CHESTER,[61] in 1890, describes the gabbros, gabbro diorites, and hornblende schists of Delaware and their relations to the surrounding rocks. The gabbro, gabbro diorites, and hornblende schists are found to grade into one another by imperceptible stages; the two latter are regarded as a metamorphosed product of the former, and all as of igneous origin. These rocks are found at various points in contact with the mica schists and gneisses. Where the eruptive rocks have a schistose structure, this is in apparent conformity with the foliation of the mica schists. Sometimes the mica schists appear to dip beneath the eruptive rocks, and at other times to overlie them. No evidence was found of any bedding not coincident with the cleavage. The unconformity discovered by Hall between the trappean rocks and the mica schists in Delaware County, Pa., was not found on the Delaware side of the line. If the horizontal bedding described exists, it is so obscured as to be unrecognizable; if the mica schists are considered to lie horizontal, the eruptive character of the gabbros, gabbro diorites, and hornblende rocks is but the more evident.

SECTION 5. NORTH CAROLINA.

SUMMARY OF LITERATURE.

OLMSTED,[62] in 1824, describes as parallel with the freestone and coal formations a great slate formation, about 20 miles wide, which extends across the State from northeast to southwest, running through Person, Orange, Chatham, Randolph, Montgomery, Cabarrus, Anson, and Mecklenburg counties. Within this district are found numerous beds of porphyry, soapstone, serpentine, greenstone, and whetstone. From Halifax to Person court-house hardly any kind of rock but granite is met.

OLMSTED,[63] in 1825, more fully describes the great slate formation, which includes argillite, greenstone, porphyry, novaculite, petrosilex, hornstone, black steatite, syenite, etc. Between the great slate formation and the Blue Ridge are a granitic district, various limestone beds, and a Transition formation. The granitic district occupies the whole country, with subordinate exceptions, from the slate formation to the Blue Ridge. The term granitic, as here used, embraces gneiss and mica slate as well as granite. Among the subordinate beds none are so numerous as greenstone. In Stokes and Surrey, in connection with the iron ores, are numerous isolated beds of limestone which lie in mica slate rocks.

MITCHELL,[64] in 1829, states that of the Primitive rocks of North Carolina the more ancient lie farther west and the more recent in the midland counties. Those of the eastern division are highly crystalline in structure, consisting of gneiss, slate, and schist, with some granite, while those of the western division are almost exclusively granite.

The Transition argillite is widespread, and in it occur most of the gold mines.

MITCHELL,[65] in 1842, describes as Primitive formations the granites, gneiss, mica slate, chlorite slate, hornblende slate, and talcose slate, quartz rock, serpentine, and limestone. A vast body of granite traverses the State in a northeast-southwest direction, comprising a large part of Person, Caswell, Orange, Guilford, Randolph, Davidson, Rowan, Cabarrus, and Mecklenburg counties; also some of Lincoln, Iredell, Davie, Stokes, and Rockingham counties. Within this belt is no well-defined gneiss, micaceous Primitive slate, serpentine, or limestone. West of this formation are the most ancient Primitive rocks, on the upper waters of the Dan, Yadkin, Catawba, and French Broad. Here are a great variety of granites. Gneiss and slate also occur. All of these are interstratified. Limestones are found at three points in Stokes County. In Anson and Richmond counties is a beautiful porphyritic granite. East of the red sandstone in the counties of Cumberland, Wake, Granville, Warren, Franklin, Nash, Johnston, Halifax, and Northampton is another body of ancient Primitive rock in which granite prevails.

EMMONS (E.),[66] in 1856, gives a systematic account of the crystalline rocks of North Carolina. Rocks of igneous origin are often massive, but also frequently are laminated, and laminated rocks are frequently called stratified, but this term should be restricted to the sedimentary rocks. The metamorphic rocks are excluded from the sedimentary classification because all rocks may become metamorphic, and a stratum metamorphic in one locality may not be metamorphic in another. The highest proof of the age of rocks is the order of superposition. When this method can be applied it is paramount, but paleontology may be used subject to proper principles. At the base of the Paleozoic, under the Silurian, is placed the Taconic.

The granitic formations are regarded as eruptive or pyrocrystalline. They form two continuous belts, which cross the State in a northeast-southwest direction. The eastern one is the Raleigh belt, and the western one the Salisbury and Greensboro belt. Granite is generally the underlying rock, but there are cases on record in which it is shown that it is an overlying one. At Warrenton, in Warren County, of the Raleigh belt, it is found to overlie gneiss, mica slate, and hornblende, where it is considered to have been projected through fissures in these rocks. This eastern belt contains no metallic veins, nor is it cut by trap or other intrusive rocks. Its breadth is from 20 to 25 miles.

The Salisbury granite is frequently syenitic—that is, hornblende takes the place of mica. This belt is cut by numerous peculiar dike rocks, in which, when they decompose, the hornblende trap appears in dark-green stripes, and many, when carefully examined, have assumed the structure of a sediment or a laminated rock, often appearing like the dark-green slates of the Taconic system. This singular structure of an eruptive rock is interesting and important, as it proves that it may be produced in rocks which have been regarded as sediments but which are the farthest removed from rocks of this description and with which water has had nothing to do. The laminæ are sometimes as thin as paper, and from their appearance can not be distinguished from the slates referred to. These dikes are bounded by walls of granite, and are frequently only from 6 to 10 inches wide. The mineral veins are generally found on the borders of the granite areas, usually within 1 or 2 miles of the slate. This western belt is 10 to 14 miles wide.

Among laminated pyrocrystalline rocks are placed gneiss, mica schist, talcose slates, hornblende, and certain limestones. It is difficult to determine the line of demarcation between gneiss and granite, as frequently there are passage beds connecting one with the other. As to the pyrocrystalline limestones, they certainly occur among the gneiss, mica slate, and hornblende rocks, with laminæ parallel with them, yet they have many characters which belong only to the eruptive rocks.

Resting upon the laminated pyrocrystallines, with the granite as a substratum, are rocks of sedimentary origin which are supposed to be Azoic. Above these are other rocks which have been in the past regarded as Azoic, but are now found to be fossiliferous. The older deep-seated sediments are sometimes distinguished with difficulty from the true Primary series, their lithological characters very often belonging to the same order. Indeed, the only proof that these rocks are sedimentary is their association with conformable pebbly beds.

The Taconic rocks are divided into lower and upper parts. The lower series contains talcose slates with white and brown sandstones and quartz, and granular limestones and associated slates, and with these occur hornblende, which makes it difficult to determine where the Primary rocks end and the Taconic begins, especially when the pebbly beds are absent. Vitrified quartz can not be regarded as always an igneous product, but rather as a deposit of silica from chemical solution. The materials composing the belts of detritus are apparently derived from the granites, as shown by the fact that the quartz and feldspar of these rocks are distinguishable in the brecciated conglomerates.

KERR,[67] in 1867, finds that the slates of western North Carolina have an average strike of N. 50° E., the dips being high to the southeast, for the most part about 65°. The greatest variations in strike and dip are in the central area, where the strata are contorted and folded to an unusual degree. This region extends from the Black Mountains to the southeast corner of Clay County. This central area is the axis of the State and is composed for the most part of granitic and gneissic rocks which are extremely metamorphosed. These rocks, as well as the slates and schists, belong to the most ancient of the Azoic series, and the Black Mountains are the oldest part of this Azoic.

KERR,[68] in 1875, gives a systematic account of the geology of North Carolina. The Azoic rocks are divided into Huronian, Laurentian, and igneous. With the Huronian are placed the siliceous and argillaceous slates and conglomerates, micaceous and hornblendic slates and schists, chlorites, quartzites, and diorites, with cherty, jaspery, and epidotic beds, and much specular iron ore. The Laurentian includes gneiss, granite, hornblende slates, etc., while the igneous includes granite, syenite, porphyry, etc.

The Laurentian occurs in four areas. The Raleigh area is a belt 20 or 25 miles wide, running northeast from this place to the State line, and consisting of light-colored and gray gneisses which occasionally pass into granite. These are cut by coarse syenite and diorite dikes. The second, the Salisbury granite area, is from 10 to 30 miles wide, and has an area of about 3,000 square miles. The prevalent rocks are syenite, dolerite, greenstone, amphibolite, granite, porphyry, and trachyte. In it there is no well-defined gneiss, mica slate, serpentine, or limestone. The large area of Mecklenburg syenite is regarded as the oldest rock of North Carolina, the bottom of the Laurentian. West of the Salisbury area is the largest connected area of Laurentian in the State, covering not less than 16,000 square miles. It closely resembles the Raleigh area, especially in the southeastern part, where it consists of a succession of schists, gneisses, and slates, for the most part thin bedded, and only occasionally showing granite-like masses and syenites, which are generally in the forms of dikes. Belonging with this series are probably the interstratified crystalline limestones of Forsyth, Yadkin, and Stokes. The outcrops are generally limited to 2 or 3 rods in thickness, a few hundred yards in length, and seem to graduate into the neighboring gneisses. The fourth considerable area of Laurentian rocks, occupying an area of 3,000 or 4,000 square miles, is west of the Blue Ridge, between this range and the Smoky Mountains. This is probably a continuation of the preceding belt, being separated from it by a narrow belt of Huronian slates, and, like it, containing crystalline limestones.

The Huronian follows the Laurentian without a break of geological continuity. These rocks are found in five principal lines of outcrops, viz: East of the Raleigh Laurentian; between the Raleigh and the Salisbury granite; west of the Salisbury granite, the Kings Mountain belt; the Blue Ridge mountains; and the Great Smoky Mountains, called the Cherokee slates. These belts are placed with the Huronian because they succeed the Laurentian and because they differ from it in degree of metamorphism and lithological character, so that the change from one to the other is obvious along the whole line of contact. The slates included are often highly plumbaceous, sometimes containing as high as 50 per cent of graphite, and the belts also contain beds of coarse granular limestone, in which is tremolite as well as magnetic iron in bedded veins sometimes 20 feet in thickness. Conglomerate belts are common. The second Huronian area is the largest, is from 20 to 40 miles wide, frequently contains quartzite, which often passes into conglomerate, and in it are most of the mineral veins. The western dips prevail, but in the western part of the tract the dip is east for several miles. This belt is bounded on both sides by the Laurentian, on which it lies unconformably and from it its materials were derived. This is the principal area of Emmons's Taconic. Safford and Bradley have concluded that the western Huronian area is Potsdam and sub-Potsdam. If this turns out to be Silurian it is probable that the Cherokee, Blue Ridge, and Kings Mountain belts are of the same age and therefore post-Huronian.

Furman,[69] in 1889, describes a section through Kings Mountain, running from 5 miles northwest, and another from the old gold mine to the granite. The rocks have a high inclination and consist of interstratified quartzite, limestone, mica slate, etc., cut by dikes of trap and greisen veins.

Nitze and Hanna,[70] in 1896, in a description of the gold deposits of North Carolina, map and discuss the crystalline rocks. The Carolina slate belt includes: (1) Argillaceous, sericitic (hydromicaceous), and chloritic metamorphosed slates and crystalline schists; (2) sedimentary pre-Juratrias slates; (3) ancient volcanic rhyolites, quartz porphyries, etc. (flint, hornstone, etc.), and pyroclastic breccias, often sheared.

This area of metamorphic slates and schists embraces a belt extending in a general southwesterly direction across the central part of the State, and varying in width from 8 to 50 miles. It is bounded on the west by the central igneous area (Emmons's pyrocrystalline rocks, Kerr's Lower Laurentian), and on the east for the greater part by the Juratrias; also in the northern part by a small area of Archean rocks (Kerr's Upper Laurentian), and in the southeastern part by a small embayment of the Coastal Plain. This is the so-called "great slate belt" of Olmsted, the "Taconic" of Emmons, and the "Huronian" of Kerr. The rocks of this belt must in time be differentiated and recorrelated, when they have been more carefully studied.

Along the extreme western edge of the State, from Mitchell to Cherokee County, the quartzites, slates, limestones, and conglomerates (here also in a great measure sheared and metamorphosed) which constitute Kerr's western Huronian belt of "Cherokee slates," have been referred to the "Ocoee" by the recent work of the United States Geological Survey.

Emmons was, in a measure, correct in calling the Taconic rocks of central North Carolina the bottom sediments and placing them below the Silurian. The absence of fossils in the slates, however, necessitates our going back still another step and placing them below the Cambrian sediments, in the Algonkian, which Van Hise has defined as including all recognizable pre-Cambrian clastics and their equivalent crystallines, the base of the Cambrian being placed below the *Olenellus* fauna. Here the matter must rest until we can find fossils in the rocks, or verify the organic character of Emmons's *Paleotrochis;* or until we can trace the rocks into a terrane of known age. So also the pyroclastic volcanics must be looked upon as pre-Cambrian.

KEITH,[71] in 1903, describes and maps the geology of the Cranberry quadrangle of North Carolina and Tennessee, along the junction of the Piedmont Plateau and the Blue Ridge. Archean and doubtful Algonkian rocks occupy all but the northwest corner of the area. The Archean rocks are mapped and described under the heads Carolina gneiss, Roan gneiss, soapstone, Cranberry granite, Blowing Rock gneiss, and Beech granite. The Carolina gneiss is the oldest rock of the region and consists of interbedded mica schist, mica gneiss, and fine granitoid layers. The Roan gneiss consists of hornblende gneiss, hornblende schist, and diorite, with some interbedded mica schist and gneiss, all cutting the Carolina gneiss. Soapstone, resulting from the alteration of peridotite and pyroxenite, occurs in bodies closely associated with the Roan gneiss and probably of the same age. The Cranberry granite is the most extensive formation in the district, occurring chiefly in the mountain district. It consists of granite and of schist derived from granite, and cuts the Roan gneiss and the Carolina gneiss. All of the rocks named are cut by the Blowing Rock gneiss and the Beech granite, which are considered to be of the same age.

Four formations are classed as doubtful Algonkian: Linville metadiabase, altered greenish diabase and gabbro; Montezuma schist, including blue and green epidotic schist, probably altered basalt, and amygdaloidal basalt; Flattop schist, a gray and black schist, probably altered andesitic rocks; metarhyolite, grayish metarhyolite, and rhyolite porphyry. The first of these appears to be the lower part of a surface flow; the last three are of surface volcanic nature.

KEITH,[72] in 1904, maps and describes the geology of the Asheville and Greenville quadrangles of Tennessee and North Carolina. Pre-Cambrian rocks occupy all the southeastern part of the area. They are igneous and metamorphic rocks much folded and of complex distribution. Those referred to the Archean are, from the base up:

Carolina gneiss, including interbedded mica gneiss and mica schist, coarse and fine, bluish gray and gray, small beds of hornblende gneiss, large bodies of garnet schist and cyanite schist, and dikes of biotite granite, both altered and unaltered; Roan gneiss, including hornblende gneiss and schist, with some massive and schistose diorite, many beds of mica gneiss, mica schist, and hornblende-mica gneiss, and dikes of altered and unaltered biotite granite; metagabbro, including dark-green and black, massive metagabbro; soapstone, dunite, and serpentine, dunite in part serpentinized, and soapstone containing talc and tremolite; Cranberry granite, including biotite granite and granite gneiss, coarse and fine, colors light gray, dark gray, and white, dikes of schistose and unaltered diabase, fragments of hornblende gneiss, and dikes of unaltered, fine biotite granite; Maxpatch granite, including coarse biotite granite, usually massive, but in places porphyritic and altered to augen gneiss, colors usually light gray in the eastern areas and reddish in the western. Assigned to the Algonkian (?) are later igneous rocks, including metadiabase and metarhyolite.

WATSON,[73] in 1904, maps and petrographically describes the granites of North Carolina.

KEITH,[74] in 1905, maps and describes the geology of the Mount Mitchell quadrangle, in North Carolina and Tennessee. The oldest rock is the Carolina gneiss, of unknown origin, assigned to the Archean, occupying the larger part of the quadrangle. Intrusive into it are the Roan gneiss, Cranberry granite, Henderson granite, soapstone, dunite, and serpentine, also assigned to the Archean. A single belt of conglomerate, graywacke, and similar rocks of unknown age surrounded entirely by the Carolina gneiss lies in the south-central part of the quadrangle. Between it and the adjoining Carolina gneiss there is apparent conformity. Overlying all are Cambrian rocks.

PRATT and LEWIS,[75] in 1905, in connection with a description of the corundum of western North Carolina, briefly describe and map the distribution of the pre-Cambrian rocks of the area, especially the peridotites.

GRATON and LINDGREN,[76] in 1906, report on a reconnaissance of gold and tin deposits of the southern Appalachians, centering at about the middle of the North Carolina-South Carolina boundary line and including parts of Cleveland, Lincoln, Gaston, and Union counties in North Carolina and of Union, Cherokee, York, Lancaster, and Chesterfield counties in South Carolina.

The rocks of this area belong to three great classes—igneous, sedimentary, and metamorphic. Sedimentary and igneous rocks of great age have been much contorted and folded. The forces producing and attendant on these movements have extremely metamorphosed the rocks, converting them into schists. Volcanic rocks, mainly represented by bedded tufts, covered these metamorphosed rocks in places and were themselves subjected to a part of the metamorphosing influences. Into these metamorphic rocks later igneous material has been intruded. Granite is the most abundant of these igneous rocks, and the numerous dikes of pegmatite are probably closely connected with it. Diabase dikes cutting all the foregoing rocks are the last representatives of intrusion. On the eastern border of the area the solid rocks are covered by thin beds of sand, which probably belong to the Coastal Plain formations.

It seems probable that the rocks of this area belong to the same pre-Cambrian complex as those of the Cranberry district to the northwest, and are assigned to the pre-Cambrian. The major subdivisions are similar to those mapped by Keith in the Cranberry and other areas.

Keith,[77] in 1907, describes and maps the rocks of the Nantahala quadrangle, in North Carolina and Tennessee. The rocks assigned to the pre-Cambrian occupy the southeastern part of the quadrangle. The oldest formation is the Carolina gneiss, consisting of mica schist and mica gneiss, of unknown origin. Intrusive into this are granite, gneiss, diorite, and other rocks. Resting upon it unconformably are sandy sediments referred to the Cambrian. *Olenellus* fauna are found in adjacent quadrangles as far as the middle of the group. The Great Smoky conglomerate and the Hiwassee slate are the formations supposedly below the *Olenellus* horizon.

Keith,[78] in 1907, maps and describes the geology of the Roan Mountain quadrangle, in Tennessee and North Carolina. Pre-Cambrian metamorphic and igneous rocks occupy the southeastern portion of the area, the metamorphics as a whole lying to the southeast of the igneous areas. The oldest rocks are the Carolina gneiss, consisting principally of mica gneiss and mica schist of unknown origin. Intrusive into this are, in order of age, the Roan gneiss, soapstone, dunite and serpentine intrusives, Cranberry granite, and Beech granite, all much metamorphosed under deep-seated conditions. Resting unconformably upon them with obviously a great time interval are surface lavas, called the Linville metadiabase and metarhyolite, constituting a great series of small dikes and sheets that are too small to be separately shown on the map. The break between them and the Archean is believed to be more important than that separating them from the Cambrian, and they are therefore provisionally classed as Algonkian. A great southeastward-dipping thrust fault was developed before the Appalachian folding, and this fault plane was further folded and faulted during Appalachian folding.

SECTION 6. TENNESSEE.

SUMMARY OF LITERATURE.

TROOST,[79] in 1840, describes the Primordial rocks of Tennessee as occurring in detached areas along the eastern side of the State. These are granitic and are associated with graywackes, which are fossiliferous. The State line is approximately the dividing line between the crystallines and the fossiliferous rocks.

OWEN,[80] in 1842, states that the metamorphic rocks in the Unaka Mountains dip at a high angle toward the granitic rocks. These relations are supposed to be due to dislocations.

CURREY,[81] in 1857, states that the Great Smoky Mountains are of granite, gneiss, mica slate, talcose slate, and quartz rock. The sandstones, shales, and slates on the western descent of the mountains are regarded as Primitive or metamorphic. They are in an inclined position, dipping inwardly toward the center of the mountain, the Primordial rocks appearing to overlie them. No anticlinal or synclinal axes are found, and the tilting is explained by faults.

SAFFORD,[82] in 1869, places the lowest formations of Tennessee as Potsdam and metamorphic. The Ocoee group is at the base of the Potsdam and is, so far as known, Eozoic. The metamorphic formations are altered rocks, Azoic or Eozoic in part, mountain making, and many thousand feet thick. They include the talcose slate, in part, of Beech Mountain and Slate Face, in Johnson County; gneissoid rocks of Stone Mountain; the syenitic gneiss of Roan Mountain; the gneiss and mica schist of the Great Bald, and the talcose slates and hornblendic beds of Ducktown.

The Ocoee or basal division of the Potsdam is semimetamorphic, Eozoic, mountain making, and has a thickness of 10,000 feet. Equivalent with this are the slates and conglomerates of Monroe County, Little Tennessee River, the west fork of Little Pigeon, of Sevier County, of the French Broad in Cocke County, of Big Butt, and of Laurel Gap of Iron Mountain. The metamorphic rocks occur in stratified beds and are mostly of the variety called gneiss or stratified granite. The line of separation between the metamorphic rocks and those to the west is sometimes well defined, but often poorly, the rocks gradually losing their crystalline characters and running insensibly into the adjacent conglomerates and slates. The general line of separation conforms to the Appalachian ridges. The metamorphic beds and the other groups all appear to follow the same law of dip and strike. The dip is in the main at a high angle to the southeast. The author has not been able to satisfy himself as to want of conformableness in the beds, although in Johnson County the metamorphic gneiss comes abruptly against the limestone; and other similar cases occur; but these unconformable junctions are naturally referable to local fractures and displacements, and this unconformableness is local and not the rule. There is no reason for believing that the metamorphosed beds include formations of any more recent date than the Ocoee conglomerates and slates, and a portion of them are certainly referable to this group. The remainder, although conformable, may be, and most likely are, older. The transitions from the slates and conglomerates to the gneiss and mica schists are well seen at Ducktown and at the Ocoee. There is no sufficient reason for referring any of these rocks to the Huronian or the Laurentian.

Bradley,[83] in 1875, describes sections in East Tennessee from Athens to Murphy and from Knoxville to Murphy. The rocks include semimetamorphosed slates, like those of Ocoee, quartzites, crystalline limestones, and gneisses, all being regarded as probably of Silurian age, with the possible exception of the massive granite at Marietta, Cobb County, Ga. The Silurian rocks thus include the Taconic and pyroclastic rocks of Emmons.

Keith,[84] in 1895, maps and describes the geology of the Knoxville quadrangle, in Tennessee and North Carolina, and of the Loudon quadrangle, in Tennessee. Ocoee rocks form the mountain areas. From the base upward the series comprises the Wilhite slate, Citico conglomerate, Pigeon slate, Cades conglomerate, Thunderhead conglomerate, Hazel slate, and Clingman conglomerate.

The Wilhite slate is bluish-gray or black argillaceous slate. In its upper portion it becomes calcareous, and contains numerous beds of limestone and limestone conglomerate. The thickness is ordinarily from 300 to 400 feet. The Citico conglomerate is entirely siliceous, and varies from fine white sandstone to coarse quartz conglomerate, with a few thin beds of sandy shale. The Pigeon slate is mainly an argillaceous slate of great uniformity, occasionally banded by thin seams of coarser siliceous material. The thickness varies from 1,300 to 1,700 feet.

The Cades conglomerate, Thunderhead conglomerate, Hazel slate, and Clingman conglomerate are not described for the Loudon quadrangle.

In the Knoxville quadrangle the Cades conglomerate consists of thick beds of slate, sandstone, graywacke, and conglomerate. The apparent thickness is 2,400 feet, but this may be an overestimate, because the formation may be repeated by folding. The Thunderhead conglomerate consists of a series of conglomerates, graywackes, and sandstones, with many small beds of slate. The thickness is believed to be about 3,000 feet. The Hazel slate is chiefly a black slate, but it contains many thin beds of sandstone and conglomerate in small quantity. The exact thickness can not be ascertained, but it is believed to be about 700 feet. The Clingman conglomerate is the same in composition as the Thunderhead conglomerate, except that in the Clingman conglomerate there is smaller development of slate beds.

The age of the Ocoee rocks is undetermined, and they are therefore mapped as of unknown age.

HAYES,[85] in 1895, maps and describes the geology of the Cleveland quadrangle, in Tennessee. Ocoee rocks occupy the southeastern part of the quadrangle, forming Big Frog Mountain and the plateau along its western base. No fossils have yet been found in these rocks, and they are separated by a great fault from rocks of known age, so that their position in the stratigraphic column can not be fixed with certainty, but since they bear the marks of extreme age they are considered as probably Algonkian. The Ocoee series comprises in this area the following formations, from the base upward: Wilhite slate, Citico conglomerate, Pigeon slate, and Thunderhead conglomerate and slate. Their correlation with formations bearing the same names in the Knoxville quadrangle to the northeast, described by Keith, is only approximate. The Wilhite slate consists in the main of dark-blue or black slate. The Citico conglomerate varies from a coarse, massive conglomerate to fine-grained sandstone or quartzite in sandy shale. The thickness varies from 500 to 1,150 or more feet. The Pigeon slate resembles the Wilhite slate, the chief difference being a frequently observed banding and an abundance of interbedded gray schistose sandstones and graywackes, and occasional conglomerates. The Thunderhead conglomerate and slate can be separated into three divisions. The lowest of these, from 800 to 1,000 feet thick, is a massively bedded conglomerate, made up largely of blue quartz and feldspar pebbles. The middle division consists of interbedded black slate and schistose conglomerate or sandstone, the slate apparently predominating. The upper division is also composed of conglomerate and slate, but the slate is comparatively unimportant.

SECTION 7. SOUTH CAROLINA.

SUMMARY OF LITERATURE.

RUFFIN,[86] in 1843, describes as Primitive the limestones which enter South Carolina at York, west of Kings Mountain, and run to Spartanburg. Embracing nearly all the country above the lower falls of the river is a granitic region.

TUOMEY,[87] in 1848, gives a report of the geology of South Carolina. The unstratified or igneous rocks underlie the stratified rocks, or are pushed up through them, and include granitic and basaltic rocks, being generally found in the form of dikes. Discordances between slaty cleavage and bedding are found. The crystalline structure of the Primary stratified rocks is supposed to be due to heat which comes from the contact of the underlying intensely heated granite. These formations have no invariable order of superposition, although they generally overlie one another in the following manner: Clay slate, talcose slate, mica slate, hornblende slate, gneiss; and associated with these are also beds of limestone, quartz, chlorite, slate, and soapstone.

A very massive gneiss, known as "table rock," on the west side of Saluda, rests unconformably upon the slates, and is regarded as evidence of the prior deposition of the slates, and also as evidence of a time break between the two. The mica slates pass by insensible gradations into the talcose slates. The lime rock is interlaminated both with gneiss and with mica slates, the latter occurring at Kings Mountain. The quartz rocks are regarded as residual material left by the disappearance of the micaceous and talcose portion of the rock. It sometimes passes into a conglomerate-like phase, but this is a step on the way toward complete crystallization. The quartz rock at times passes into itacolumite. The magnetic and hematitic ores are associated mostly with the slates and limestones, and appear as beds interlaminated with and grading into them.

LIEBER,[88] in 1858, describes the rocks of the Chester and York districts. They are divided into clay slate, which includes limestone, itacolumite, and specular schist; and hornblende slate, which includes talcose slate and mica slate. The first class, which may possibly be Paleozoic, appears wherever the Tertiary deposits have been removed by erosion. It has a dip unconformable to the talcose slate. Itacolumite is described, and below it at times is found specular schist and above it limestone. The igneous rocks are divided into trachytic, trappean, and granitic rocks. The trachytic rocks include eurite, quartz porphyry, coarse trachyte, domite, and phonolith; the trappean rocks include diorite, diorite slate, soapstone (?), talcose trap (?), melaphyre, and aphanitic porphyry; the granites include coarse-grained granite, syenite, and other granite and gneiss.

LIEBER,[89] in 1858, divides the rocks of Union and Spartanburg into Super-itacolumite, Itacolumite, and Sub-itacolumite groups. The first includes limestone. The second includes itacolumite with talcose slate, limestone, specular schists, and itacolumite conglomerate. The third includes clay slate, talcose slate, mica slate, and gneiss. There is no definite proof that the gneiss occupying the lowest position is of sedimentary origin. Indeed, there is greater probability that it is, strictly speaking, a granite having a parallel distribution of the scales of mica. It passes into the ordinary granite, with no distinct boundary between the two. The mica slate overlying the gneiss is of insignificant thickness, as shown by the fact that mining shafts and streams frequently cut through it to the gneiss. The dip of the slate is almost always constant to the southwest. It is the predominant position in the country for the metalliferous veins. The itacolumite is described in detail. The conglomerate-like itacolumites, mentioned by Tuomey, are regarded as real conglomerates, with a micaceous and arenaceous cement. The pebbles are obscured and elongated, the longest diameters being parallel to the bedding, and they also partake of the schistose structure of the matrix in which they are contained. Every stage in the passage from the fine-grained rock to the conglomerate with pebbles is seen, and there is no question that the itacolumite is a sandstone. The eruptive rocks include granites, eurite, and trappean rocks, among which are schistose aphanite, aphanitic porphyry, minette, diorite, diorite slate, and saponite. That the schistose rocks here included are really eruptive is shown by the manner in which they intrude the granitic rocks.

Lieber,[90] in 1859, gives a general account of the rocks of South Carolina. The peculiar structure of the schistose aphanites is regarded as due to weathering. In the Greenville and Pickens districts the succession includes gneisses, limestones, and mica schists, the ruling dips being southeasterly. Tuomey's representation of these rocks as 60 to 70 miles thick is believed on theoretical grounds to be incorrect. The ruling southeasterly dip of the slates is probably due to faults which have repeated the stratified rocks many times. It is concluded that the isolated bodies of stratified rocks overlying the gneiss are actually islands occupying, with much regularity, the apical lines of certain parallel ridges. It can not be asserted that any of the mica slate beds exceed 100 feet in thickness and the horizontal slates 25 feet. The talcose slate below the itacolumite is frequently highly graphitic. Above the talcose slate is limestone, and above this the itacolumite, the outlines of the latter being extremely tortuous. The dike rocks are aphanite, porphyritic hornblende rock, eurite, and garnet. A detailed account of itacolumite is given.

Lieber,[91] in 1859, definitely states that itacolumite is regarded as occupying a constant position, and is taken as a starting point upon which to determine the chronology of the Azoic rocks of the southern Alleghanies.

See also North Carolina, section 5 of this chapter.

SECTION 8. GEORGIA.

SUMMARY OF LITERATURE.

Peck,[92] in 1833, divides the mountain-region rocks into Primitive and Transition, the first being on the west, and the boundary between the two being the Smoky Mountains.

Cotting,[93] in 1836, divides the Primary formation into granite, syenite, porphyritic granite, gneiss, mica slate, talcose slate, granular limestone or marble, serpentine, greenstone, epidotic gneiss, quartz rock, hornblende, and clay slates. The granite passes by imperceptible gradations into the gneiss, beds of the two sometimes alternating, and the latter also passing into the stratified mica slate. Gneiss also passes into the stratified mica slate, and the mica slate into talcose slate. The graywacke is the beginning of the transition.

LITTLE,[94] in 1875, mentions crystalline rock, presumably Primary, at various points.

CAMPBELL (J. L.) and RUFFNER,[95] in 1883, divide the Archean, upon chemical, lithological, and structural grounds, into Laurentian and Huronian. In the metamorphosed rocks the prevailing dips are toward the southeast. It is believed that while they were somewhat plastic they were folded and overturned, although in places left in a vertical position; and not infrequently they are found in a nearly horizontal position, or sometimes resting in arches and depressions. In the Choccolocco Valley the railroad passes abruptly to the Lower Silurian rocks. This relation between the Silurian and the Archean is attributed to a fault, with downthrow of the former.

ELLIOTT,[96] in 1883, states that the mica schist and gneiss at Jasper dips beneath the marble and is therefore metamorphosed Knox sandstone. The porphyritic gneiss of the West Atlantic Railway is identical with that at Talking Rock, and is a metamorphosed form of the Ocoee sandstone.

KING,[97] in 1894, describes the geology of the "Crystalline belt" of Georgia in connection with the occurrence of corundum. The Crystalline belt occupies an area of 12,430 square miles, crossing the northern part of Georgia from the northeast to the southwest, and lying between Paleozoic strata in the northwest corner of the State and Mesozoic and Cenozoic strata in the southern half of the State.

The rocks of the Crystalline belt are divisible into two petrographical classes. The first consists of a series of mica schists, slates, shales, conglomerate, and marble, which, though more or less crystalline, show evidence of clastic character. This class is called the semicrystalline series. The semicrystalline rocks are confined to an area bordering the Paleozoic to the northwest. The second class comprises eight types of rock. Three of them, limestone, quartzite, and slate, are undoubtedly clastic; three of them, granite, gneiss, and mica schist, are completely crystalline and show no trace of clastic character; and two, peridotite and diorite, are presumably of eruptive origin. Gneiss and mica schist are the prevailing rocks. This second class is termed the holocrystalline series.

The rocks of the Crystalline belt are separated from the Paleozoics on the northwest by a strong unconformity. Between the semicrystalline and holocrystalline rocks there is apparent transition.

Throughout the Crystalline belt there is a uniform dip to the southeast, pointing toward a moving force from the southeast, but in the holocrystalline area the dip is much steeper than in the semicrystalline area. Disturbances and alterations are more extensive in the holocrystalline rocks than in the semicrystalline rocks. Corundum is present only in the holocrystalline rocks.

From these facts it is believed that the holocrystalline area is older than the semicrystalline area, and formed the continent against which washed the waters of the sea which deposited the rocks of the semicrystalline series. While a portion of the holocrystalline series may be Archean, because of the presence in it of undoubted clastics the series is referred to the Algonkian. The same reference is made for the semicrystalline rocks.

The history, varieties, and characters of corundum, and its mode of occurrence in the holocrystalline rocks, are fully described.

JONES,[98] in 1901, in connection with a description of Tallulah Gorge, in northeastern Georgia, describes the crystalline rocks there occurring and gives a little sketch map showing their relations. They are called pre-Cambrian.

WATSON,[99] in 1901, describes the granitic rocks of the Piedmont Plateau of Georgia. Field and laboratory studies indicate that they are not all contemporaneous in origin. Some of them are pre-Cambrian, while others may possibly be later in age. The composition of the gneisses shows them to be of igneous origin.

SECTION 9. ALABAMA.

SUMMARY OF LITERATURE.

TUOMEY,[100] in 1850, places the granites, gneisses, and associated crystalline rocks as Primary and metamorphic. The slates sometimes carry plumbago, and true granite is found only at Talladega.

TUOMEY,[101] in 1858, finds in various sections granite, syenitic gneiss, ordinary gneiss, hornblende slate, mica slate, talcose slate, and soapstone. In certain localities are found limestones, and also occasionally interstratified quartz rocks occur. Granite is found about Rockford in large masses.

SMITH,[102] in 1875, states that the counties of Chilton, Talladega, Calhoun, Cleburne, Lee, Tallapoosa, and Elmore lie partly, and Coosa, Clay, Randolph, and Chambers wholly, within the Archean region of the State. On account of the absence of fossils, it is difficult to determine the relative ages of the subdivisions of the crystalline rocks. Lithologically they are classified into Laurentian, Huronian, and White Mountain series, following Hunt's characterization of these terms. The rocks here included are granite, gneiss, mica schist, mica slate, hydromica slate, clay slate or argillite, syenite, syenitic gneiss, hornblende schist, diorite, norite, talcose slate, soapstone or steatite, chlorite schist, quartzite, siliceous slate, itacolumite, itabarite, jasper, crystalline limestone, dolomite, and igneous rocks. Crystalline limestone occurs in Chilton County. It is succeeded in apparent conformity by semicrystalline rocks 15,000 to 20,000 feet in thickness.

SCHMITZ,[103] in 1884, describes a metamorphic region in Alabama as covering the whole or parts of counties Chilton, Coosa, Talladega, Calhoun, Cleburne, Lee, Tallapoosa, Elmore, Clay, Randolph, and Chambers, with about 5,000 square miles of area. The rocks of this region are partly metamorphosed Lower Silurian rocks (Calciferous, Potsdam, and Acadian), partly Upper Azoic rocks (Huronian), and perhaps partly Lower Azoic rocks (Laurentian).

Going at a right angle with the strike, from northwest to southeast, one finds the following zones, which, however, can not be sharply separated. (1) Silurian: Crystalline limestones, conglomerates, heavy quartzites, and slates (often gold bearing), semimetamorphosed. (2) Huronian: Mica slates and schists (with garnets), limestones, coarse-grained granites, diorites, quartzites, and clay slates (sometimes gold bearing); the mica schists often alternating with gneisses; associated with graphite and graphitic slates, itacolumite, specular ore, brown hematite, etc. (3) Huronian or Upper Laurentian: Gneisses (micaceous and hornblendic), granite, diorite, mica schists, quartzites, slates (sometimes gold bearing), associated with chloritic schists and steatites, mica with tourmaline crystals, etc. Some of the granites have the characteristics of eruptive rocks.

SMITH,[104] in 1896, gives a general account of the character, distribution, and structure of the crystalline rocks of Alabama. The rocks are altered sedimentary and igneous rocks. The altered sedimentary rocks, called the Talladega or Ocoee series, are referred to the Algonkian, and the altered igneous rocks are referred to the Archean.

The Talladega series is found in the northeastern part of the State, in four or five roughly parallel belts, running northeast-southwest, the strata in general dipping to the southeast. The series comprises, in order of abundance, clay slates or argillites, in places impregnated with graphite, quartzites and quartzite conglomerates, and crystalline limestones or dolomites. The slates, quartzites, and conglomerates resemble very strongly certain strata of undoubted Cambrian age, and it is probable that some of the strata included with the Talladega are altered Cambrian rocks. As yet, however, no fossils have been discovered in them.

The altered igneous rocks occur in three main belts, roughly parallel with the sedimentary belts in the northeastern part of the State. In order of abundance they are gneisses and mica schists, cut by dikes of granite, diorite, and various hornblendic, pyroxenic, and chrysolitic rocks.

Gold ores are associated with both the sedimentary and the igneous series. Their mode of occurrence is briefly sketched.

Brooks,[105] in 1896, in petrographic notes on some metamorphic rocks from Alabama, makes general statements concerning the geology of the metamorphic rocks of Alabama and Georgia. The metamorphic rocks of Alabama and Georgia may be differentiated into two series. The older, or crystalline series, includes crystalline schists and gneisses, whose origin is doubtful, together with large masses of gneissoid granite. The younger, or clastic series, is typically made up of phyllites, sericite schists, chlorite schists, conglomerates, quartzites, crystalline sandstones, and in a portion of the region limestones and marbles. The rocks of both series are closely associated with rocks of undoubted igneous origin.

SECTION 10. SOUTHERN PIEDMONT AND APPALACHIAN REGIONS (GENERAL).

SUMMARY OF LITERATURE.

Britton,[106] in 1886, describes the contact at Natural Bridge between sandstones which appear to be under the Potsdam and over the Archean. The two are widely unconformable; the sandstone dips 45° NW. and strikes N. 40° E., while the Archean dips 65° E. and strikes N. 5° E. The Archean rocks consist of quartz-bearing syenite and granulite, fragments of which are found in the overlying series.

On Doe River, in eastern Tennessee, the Archean and basal Silurian quartzite are in contact. The Archean is a pegmatite, with no bedding or lamination. Five hundred feet east of the contact it is a much contorted hornblendic gneiss and syenite. These rocks are intersected by a trap dike. The quartzite is thickly bedded and contains many pebbles of quartz and much feldspar, so as to make the rock in places an arkose.

On French Broad River are found quartzites like those of Doe River, which are succeeded by basal crystalline rocks, and near Marshall station begins a stratified micaceous schistose series. The character of the transition between this and the basal Archean rocks was not apparent. About Asheville are well-bedded gneisses and mica schists which bear the same relation to the heavily bedded basal Archean as do the Westchester County, N. Y., and Philadelphia gneisses to the basal rocks farther west. These rocks extend to the top of Mount Mitchell.

Watson,[107] in 1905, summarizes the pre-Cambrian geology of the southern Appalachians.

Virginia.—The work of the Rogers Survey, covering the years 1835 to 1841, inclusive, comprises the only geologic work that has yet been done in Virginia on the pre-Cambrian. The more important rocks comprising the Piedmont region in Virginia include, according to Rogers, granite, gneiss, syenite; micaceous, chloritic, talcose, and argillaceous schists; talcose, quartz, and argillaceous slates; soapstone rocks; micaceous and talcose limestones and marbles; pseudo-gneiss or gneissic sandstone, and quartzite. These were all considered by Rogers to be of very ancient date, mostly Primary comprising both sedimentary and igneous masses, and all highly metamorphosed.

Between the years 1874 and 1885 the principal work done in the region of the Virginia crystalline rocks was by Fontaine and J. L. and H. D. Campbell, and was confined principally to parts of the Blue Ridge region. As indicated by these geologists, the principal rock types are essentially the same as those identified by Rogers. They comprise granite, syenite, mica schists, micaceous and hornblendic gneiss, granulite, mica slates, hydromica slates, argillite, greenstone, talcose limestone, quartzites, and conglomerates. In places unconformities were noted, and the rocks were classified as pre-Silurian and assigned partly to the Laurentian, partly to the Huronian, and partly to the Primordial (Cambrian).

J. L. and H. D. Campbell described a series of sandstones and slates flanking the southeast slope of the Blue Ridge in Amherst County, the sandstones of which contained fossil borings of *Scolithus linearis*, which definitely marks them as Cambrian in age. No fossils were reported found in the slates of this series, but the *Scolithus* sandstone was observed to dip under the slates, which indicates that the latter can not be older than Cambrian. These beds, sandstone and slate, had previously been mapped as Archean.

Lower Silurian fossils have been reported by Darton and Walcott from the slates composing the Arvonia area on James River in the northeast corner of Buckingham County and east of the Amherst County area mentioned above. These slates were likewise referred to the Archean prior to the discovery of fossils in them by Darton. In the extreme northwest corner of the Fredericksburg quadrangle Darton has mapped and described a narrow belt of slates, designated the Quantico slates, which resemble the slates of the Arvonia area in Buckingham County, but, as Darton remarks, the resemblance may be fortuitous, as fossils were not found in them, and they may or may not be of the same age as those of the Buckingham area. Granites and gneisses, regarded as largely pre-Cambrian, occur on either side of the narrow belt of the Quantico slates.

In 1894 and 1901 the Harpers Ferry and Washington folios were published by the United States Geological Survey, each covering parts of the crystalline rocks in northern Virginia. The Virginia section of the Harpers Ferry quadrangle includes a part of the Blue Ridge and a part of the adjacent western margin of the Piedmont Plateau. Rocks of both sedimentary and igneous origin are distinguished. According to Keith the pre-Cambrian rocks of this area are of Algonkian age, and comprise Catoctin schist (altered diabase) and granite. No pre-Cambrian sediments are recognized.

The Washington folio covers the adjacent parts of Alexandria and Fairfax counties, Va., extending northwest, west, and southwest from the city of Washington. The crystalline rocks comprised within the Virginia portion of this district are, according to Keith, of pre-Cambrian age and are all referred to the Archean. The principal types distinguished comprise mica gneiss, mica schist, granite gneiss, diorite and metadiorite, gabbro and metagabbro, soapstone and serpentine, and biotite granite.

In 1901 Watson traced and described the continuation of a belt of ancient volcanic rocks in North Carolina northward into Halifax County, Va., and ascribed to the belt a pre-Cambrian age, probably Algonkian. The rocks comprised altered andesites and the associated tuffs, and are probably contemporaneous in age with the South Mountain volcanics of Maryland and Pennsylvania.

Excepting the several areas of Juratrias rocks which cover parts of the Virginia Piedmont region, areas of undoubted metamorphic crystalline sediments occur over parts of the region not yet mapped, of post-Algonkian age. A considerable part of the Piedmont complex, however, is composed of metamorphic crystalline rocks closely similar to those recently mapped as pre-Cambrian, comprising original igneous masses and sediments. Granites, granite gneisses, soapstone, and serpentine make up the principal types.

North Carolina.—No attempt is here made at a discussion of the earlier work on the geology of the crystalline rocks of North Carolina by Emmons and Kerr; only the more recent work since 1890 is reviewed.

The easternmost belt of metamorphic crystalline rocks in the State passes eastward beneath the Coastal Plain sediments and the narrow trough of Triassic sandstones, and was named by Kerr the Huronian belt of central North Carolina. It includes a complex of altered sedimentary and igneous masses, comprising (1) argillaceous, sericitic, and chloritic metamorphosed slates and schists; (2) devitrified ancient volcanics, rhyolite, quartz porphyry, metaandesite, etc., and pyroclastic breccias and tuffs; (3) igneous plutonic rocks, granite, granite gneisses, diorite, etc.; (4) siliceous magnesian limestones; and (5) sedimentary pre-Juratrias slates.

The chloritic schists are in part the equivalents of profoundly altered basic eruptives. They are less abundant than the argillaceous schists, and are often garnetiferous and epidote bearing. The general strike of the schistosity is N. 20° to 55° E., and the dip 55° to 85° NW.

Except a few areas of granite and more recent dikes of basic igneous rocks, principally diabase, the rocks have all been profoundly altered and rendered more or less completely schistose. In a few instances recorded observations of bedding and banding, corresponding to the original bedding planes, have been noted, extending across the schistosity of a part of the schistose rocks at generally low angles. The schistosity of the rocks composing this belt conforms broadly to a general northeast-southwest strike, with steep dip to the northwest. Local departures from these directions are numerous. This belt composes Emmons's Taconic and Kerr's Huronian.

Complete differentiation of the rocks has not been effected, but enough petrographic work has been done to conclusively prove the presence of considerable areas of sedimentaries. A part, at least, of the argillaceous, sericitic, and chloritic schists found within the limits of the belt is of sedimentary origin. On the other hand, many of the so-called slates and schists originally classed as sedimentary by the earlier geologists are definitely proved to be of igneous origin.

Beginning at the Virginia boundary to the east of Danville, a belt of typical ancient lavas and associated tuffs of both acidic and basic types is traced across the State into South Carolina. G. H. Williams recognized in the central and northern portions of the belt felsites, porphyrites, and rhyolites, showing both spherulitic and flow structures, accompanied by pyroclastic breccias and tuffs. Devitrified acidic glasses with chains of spherulites and eutaxitic structures were collected by Williams. More recently in the northern part of the same belt, with about equal extension in Virginia and North Carolina, Watson has traced and described an area of ancient andesitic (metaandesite) lavas and associated tuffs, now profoundly altered and rendered schistose, which, in connection with their other characters, very closely resemble the typical greenstones of the Lake Superior region. Field and laboratory study refers these ancient lavas studied by Williams and Watson to pre-Cambrian age, probably contemporaneous with the lavas of South Mountain in Maryland and Pennsylvania.

Likewise recent study in the same area points to pre-Cambrian age for a part, at least, of the granites and granite gneisses which occur largely over the extreme northeastern part of the belt.

Perhaps the principal area of slates that can be shown to be of sedimentary origin is that extending over parts of Union, Albemarle, and Montgomery counties, in the southern portion of the belt. This area of slates was designated the Monroe slates by Nitze; and for the reason that fossils were not found in them they were provisionally referred by the same author to the Algonkian. Similarly the siliceous magnesian limestones of Kings Mountain, etc., have been provisionally assigned by Nitze to the Algonkian.

The greater part of the North Carolina Piedmont region is included between the eastern belt described above and the mountain region in the western part of the State. The middle belt of the Piedmont region, immediately west of and parallel to the eastern belt, is composed largely of igneous rocks, principally granites, which are now more or less schistose from dynamo-metamorphism. The mica types largely predominate, though hornblendic ones are not uncommon. Altered basic eruptives, greenstones, and greenstone schists are common, and in some places form the rocks into which the granites were intruded. Watson has indicated that probably the major part of this complex, if indeed not all of it, can reasonably be referred to a pre-Cambrian age.

Excluding several narrow bands and other irregular areas of metamorphic slates, schists, limestone, quartzites, and conglomerates of unknown age, probably Cambrian and later in part, the western portion of the Piedmont region is composed of gneisses, mapped by the North Carolina Geological Survey as probable Archean. Both micaceous and hornblendic gneisses occur, with the former greatly predominating. Over parts of the area the gneisses are regarded as passing into schists through a higher development of lamination, and include numerous masses of granitic and other distinctively igneous rocks. The gneisses have been commonly considered, in great part, to be sedimentary rocks, though a part of them are certainly granites and other original igneous rocks. The general strike of the gneisses is about N. 30° E., with a prevailing dip at a high angle toward the southeast. Local variations in both strike and dip are very numerous.

In the western, and especially the southwestern, part of the gneiss belt occur numerous small lenticular masses of basic magnesian rocks, chiefly peridotites, pyroxenites, and amphibolites, the former largely predominating, which are regarded as of igneous origin and intrusive in character.

Keith has recently mapped and described the geology of the Cranberry, Asheville, Mount Mitchell, and Nantahala quadrangles, in North Carolina and Tennessee. These quadrangles are in the mountain region and along the junction of the Piedmont Plateau and the Blue Ridge. In the Cranberry quadrangle all but the northwest corner in Tennessee is occupied by rocks of Archean and doubtful Algonkian ages. The Archean rocks mapped and described comprise the Carolina gneiss, Roan gneiss, soapstone, Cranberry granite, Blowing Rock gneiss, and Beech granite. The Carolina gneiss is the oldest rock of the area, and is of unknown origin. The five remaining formations of Archean age are regarded as of igneous origin. The formations classed as doubtful Algonkian are Linville metadiabase, Montezuma schist, Flattop schist, and metarhyolite. These are all of igneous origin and appear to be, in large part, of surface volcanic nature.

The Carolina portion of the Asheville quadrangle comprises mainly granites and gneisses, the latter of undetermined origin but probably derived from basic intrusives. Both the granites and the gneisses are mapped and classed as Archean. Dikes of rhyolite, pegmatite, quartz diorite, basalt, and dunite, with its derivatives talc and serpentine, are numerous. Lenticular beds of siliceous marble occur in the gneiss, indicating a probable sedimentary origin for parts of it. The Archean rocks mapped and described are Carolina gneiss; Roan gneiss; metagabbro; soapstone, dunite, and serpentine; Cranberry granite, and Max Patch granite. Metadiabase and metarhyolite are mapped as doubtful Algonkian. (See also summaries of Mount Mitchell and Nantahala folios, pp. 683, 684.)

Tennessee.—Within recent years much of the geology of eastern Tennessee, including the mountain areas, has been mapped and described by geologists of the United States Geological Survey—principally Keith and Hayes. The pre-Cambrian masses, largely igneous but probably sedimentary in part, mapped and described by Keith in the Cranberry and Asheville folios, extend from North Carolina into Tennessee.

Three of the quadrangles—the Knoxville, Loudon, and Cleveland—include in the mountain areas a series of sediments known as the Ocoee, of unknown age. The Ocoee rocks comprise bluish-black and gray argillaceous and calcareous slates and coarse and fine quartz conglomerate and sandstone. The formations contain so few constant characteristics and undergo so many variations that correlation is very difficult. No fossils have yet been found in these rocks. According to Hayes the rocks of the Ocoee series bear all the marks of extreme age, and for this reason as much of the Ocoee as was included in the Cleveland quadrangle was provisionally assigned as probable Algonkian, until more satisfactory evidence of the age of the rocks could be found. In earlier publications the Ocoee rocks were considered to be Cambrian and to lie under the Chilhowee rocks (Cambrian), but according to Keith there is ample evidence that they should be separated from the Cambrian in the Tennessee area, though it is not sufficient to fix their age.

In the quadrangles where there are mapped and described the Ocoee series of unknown age, the oldest rocks, definitely fixed by the finding of fossils in some of the formations, are Cambrian. The Cambrian formations are all of sedimentary origin, except a thin basaltic flow in the Cranberry region, and comprise conglomerates, sandstones, shales, and limestones.

South Carolina.—Our knowledge of the crystalline rocks composing the Piedmont region of South Carolina has not been increased in recent years, and we are largely dependent at present upon the work of the earlier geologists—Tuomey and Lieber. A similar complex of altered igneous masses and some associated metamorphic sediments, described for the adjacent parts of North Carolina and Georgia, and in part of pre-Cambrian age, makes up the corresponding parts of the South Carolina Piedmont areas. The rocks are essentially of the same types as in the other States where much detailed work has been done, comprising chiefly granites, gneisses, schists, slates, sandstones, and limestones, all greatly altered, and associated with some basic eruptive materials. G. H. Williams mapped and described several small areas of probable pre-Cambrian volcanics over parts of the South Carolina Piedmont region similar to those of North Carolina.

Georgia.—According to Hayes the southeastern portion of Bartow County, in northwest Georgia, is about equally divided between the older crystalline and metamorphic rocks of the Piedmont Plateau and the Appalachian Mountains on the east and the Paleozoic (Cambro-Silurian) sediments of the Appalachian Valley on the west. The Paleozoic sediments are referred to Cambro-Silurian age. To the east and south of the Paleozoic sediments are the metamorphic crystalline rocks of the Piedmont area, which include slates, schists, conglomerates, gneiss, and granite. The oldest of these rocks is the granite, which is mapped as pre-Cambrian. The conglomerate, slate, and schist are mapped as Ocoee, which is referred to the Algonkian, for the reason that no fossils were found in them and because they have every appearance of extreme age. The coarse conglomerate bordering the granite was unquestionably derived from the granite. Where not bordered by the coarse conglomerate the granite is in contact with black graphitic slates, which generally overlie the coarser sediments.

In this area the rocks of the Ocoee series generally show an increasing degree of metamorphism toward the southeast; and within a few miles of this region they pass into schists and gneisses, the original form of which, whether igneous or sedimentary, can not be readily determined. This increased metamorphism toward the southeast is due in part to the greater compression which that region has suffered and in part to the presence of considerable bodies of various igneous rocks which have been intruded into the sedimentary beds. The intrusive rocks present a considerable variety in composition, varying from extremely basic diabase to acidic granites. The most common variety is diorite, which was among the earlier intrusions, and has been subsequently converted for the most part into amphibolite schist. The extreme southeast corner of the mapped area is occupied by the Acworth gneiss, which, like the Corbin granite, is probably Archean in age, and formed the foundation on which the oldest sediments of the region were deposited.

According to Watson granites and granite gneisses have wide distribution over the Georgia Piedmont region. The two types differ only in the more marked foliated structure of the granite gneiss. As a rule the contorted gneiss phase is not traced into the massive type of the granite. Field and laboratory study indicates that at least two distinct periods of intrusion of closely similar acidic material are represented in the Georgia area. Most, if not all, of the granitic masses studied are believed to be pre-Cambrian, though some may possibly be later.

A number of thin bands of magnesian limestone and larger areas of sandstone or quartzite occur in places over parts of the Georgia Piedmont region. The entire or exact significance of these sedimentary masses, especially their age and their relations to the associated rocks, has not yet been determined. While King referred the rocks of the entire "Crystalline belt" of Georgia to pre-Cambrian age, it is probable that careful study of the region will reveal a post-Algonkian age for at least a part of the sedimentaries, including the limestones and quartzites mentioned above.

Alabama.—Smith describes the rocks composing the crystalline area in northeastern Alabama as including altered sedimentaries and igneous masses. The altered sedimentary rocks, called the Talladega or Ocoee series, are referred to the Algonkian, and the altered igneous rocks are referred to the Archean. The Talladega or Ocoee series occurring in the northeastern part of the State in four or five roughly parallel belts trending northeast-southwest and having a general southeast dip, comprises argillites, graphitic in places, quartzites and quartzite conglomerates, and crystalline limestones or dolomites. The slates, quartzites, and conglomerates closely resemble certain strata of undoubted Cambrian age, and it is probable that some of the strata included in the Talladega will prove to be altered Cambrian rocks. Fossils have not yet been discovered in them.

The altered igneous rocks referred to the Archean are grouped in three main belts roughly paralleling the sedimentary belts of the Talladega series. They comprise gneisses and mica schists, cut by dikes of granite, diorite, and various hornblendic, pyroxenic, and chrysolitic rocks.

Brooks, in petrographic notes on some metamorphic rocks from Alabama, differentiates the metamorphic rocks of Georgia and Alabama into two series. The older, or crystalline series, includes crystalline schists and gneisses of doubtful origin and large masses of gneissoid granite. The younger, or clastic series, is typically made up of phyllites, sericite schists, chlorite schists, conglomerates, quartzites, crystalline sandstones, and in places limestones and marbles. The rocks of both series are closely associated with rocks of undoubted igneous origin.

Clements, in a microscopical study of certain rocks from the crystalline area of Alabama, includes sedimentary and igneous rocks, and others whose origin is unknown. Disregarding the sedimentary rocks, which are comparatively unimportant, Clements regards the rocks as a whole as having characters of Archean rocks.

In 1894 Smith published a geological map of Alabama with an explanatory chart, in which the rocks of the crystalline area are mapped and described under two series. The older, characterized as fully crystalline and comprising mainly crystalline schists, is referred to the Archean. The younger, characterized as imperfectly crystalline and comprising altered sediments, is named the Talladega or Ocoee, and is provisionally referred to the Algonkian. The classification of the Talladega is marked as uncertain, probably in part Cambrian.

In the northwestern part of the Ashland quadrangle, in northeastern Alabama, fossils have been found in black shale which had been previously considered as Ocoee. The black shale is associated with Ocoee rocks, but from the evidence cited above it will possibly prove to be Carboniferous and can be correlated with a great thickness of black shale to the northwest in Georgia.

Keith,[108] in 1905, summarizes the pre-Cambrian geology of the southern Appalachians.

General relations.—Among the earlier students the Appalachian Province was tacitly limited to the Paleozoic rocks. The rocks which lie southeast of them are in the main older and more or less metamorphosed. In the latter, however, typical Appalachian folds and faults are found wherever the formations are in contrast. In the Paleozoic sediments, likewise, large masses of rock are metamorphic. The Appalachian Mountains are made up of the lowest Paleozoic rocks and various older rocks of igneous or metamorphic nature. Over the Piedmont Plateau, which joins the mountains on the southeast, many sedimentary rocks are folded in between the metamorphic beds. Wherever they have been closely studied these sediments are of Cambrian or later age, and it seems highly probable that most of the less studied sediments are of similar age. The igneous formations of the Piedmont are the same as, and often continuous with, the igneous rocks of the Mountains. From a geological point of view, therefore, there is no distinction between the Piedmont and the Appalachian Mountains, however much they diverge as topographic features.

A brief synopsis is here given of the pre-Cambrian formations in order of age. More detailed descriptions of them will be found in the Harpers Ferry, Washington, Cranberry, Asheville, Greeneville, Mount Mitchell, Nantahala, Roan Mountain, and Pisgah folios of the

United States Geological Survey. The work of Hayes farther south shows that the same series of rocks in the same relations occur in Georgia and Alabama.

Carolina gneiss.—This is the oldest formation known in the southern Appalachians. It consists mainly of mica gneiss and mica schist, with varying amounts of quartz, feldspar, muscovite, and biotite. Many layers are granitoid, others are fine schists. With these major types there are also found cyanite, garnet, and muscovite schists and gneisses. At several localities large layers of marble are interbedded with the gneiss. Thus the formation is in part of sedimentary origin, while other beds have a probable igneous origin. The nature of most of the formation is entirely unknown, however, and all varieties are thoroughly metamorphosed. The banded gneisses and schists produced during one metamorphism were folded and crumpled during another. The different layers were thickened or thinned and cut across by secondary foliation.

Roan gneiss.—Hornblende schist and gneiss make up most of the formation. With these are found bodies of diorite and gabbro, all more or less altered. These rocks cut the Carolina gneiss in intricate dikelike forms. In the Roan gneiss also the schistosity and gneissoid banding of one deformation are folded and cut by those of a second.

Soapstone group.—Dunite, serpentine, and soapstone are alteration products of peridotite and pyroxenite and are closely associated. A single rock mass may be composed of all the varieties or of one. In the great majority of cases their association with the Roan gneiss is so distinct as to show a close connection in age, although they appear to cut the Roan here and there. The dunite and serpentine are not schistose, while the soapstone and other varieties are decidedly so.

Cranberry granite.—The Carolina and Roan gneisses are cut by the Cranberry granite, which consists of coarse and fine gray and red granite. It is usually characterized by biotite and frequently shows large orthoclase phenocrysts. Much of the rock is massive, but large parts are gneissoid and in certain zones extremely schistose and striated. The foliation planes are fairly constant in dip over large areas.

Henderson granite.—This formation does not touch the other granites, but cuts the Carolina and Roan gneisses. It is characterized by orthoclase phenocrysts and muscovite. This granite is strongly schistose, both groundmass and phenocrysts being deformed. The schistose planes are remarkably uniform in dip.

Blowing Rock gneiss.—This formation cuts the Carolina gneiss and appears to cut the Cranberry granite. The formation consists of a highly porphyritic rock in which large orthoclase crystals are embedded in a dark groundmass characterized by biotite. The original rock was probably a basic, porphyritic granite. Usually it is very schistose and the phenocrysts are much broken and elongated. The foliation planes have a very constant dip in this formation.

Beech granite.—This granite cuts the Cranberry granite and the Blowing Rock gneiss. The formation consists of coarse, red or gray massive granite marked by biotite and of a very coarse, light variety with orthoclase phenocrysts. Large amounts of the rock are only slightly metamorphosed, but most of the formation is schistose. The phenocrysts are elongated and the massive varieties are striated and flattened into schists.

Max Patch granite.—The Max Patch cuts the Cranberry granite, the Roan gneiss, and the Carolina gneiss. This granite is decidedly like the Beech granite, but the two are not in contact. The varieties of each are about the same and each is metamorphosed to the same extent. It is possible that they are derived from the same magma.

Linville metadiabase.—This formation occurs in dikes cutting the Cranberry granite and the Blowing Rock gneiss, and also forms large bodies which appear to grade into the Montezuma schist. The metadiabase is of a greenish color and is composed mainly of plagioclase and hornblende. With these are much epidote, chlorite, and fibrous hornblende. In some places the original structures remain; in others the secondary schistosity and epidote lenses are most prominent.

Montezuma schist.—This formation is chemically similar to metadiabase and appears to be the upper part of the same igneous mass. It consists of fine schists and amygdaloids, of bluish or greenish color, which are composed mainly of chlorite, feldspar, epidote, muscovite, and quartz. These are all metamorphic minerals and the rock is decidedly schistose. The lenses of epidote and quartz are very prominent and often of large size. The amygdaloids are plainly vesicular surface lavas, but no traces of a glassy base remain.

Catoctin schist.—This schist is prominent in Maryland and northern Virginia and is similar in every respect to the Montezuma schist.

Flattop schist.—This rock cuts the Cranberry granite and the Blowing Rock gneiss. It consists of dark bluish or black, banded schists with some amygdaloid. The component minerals are feldspar, quartz, muscovite, and chlorite, with magnetite and epidote in certain layers. Quartz, feldspar, and muscovite form thin gray bands in the schist and represent layers of volcanic ash. Flow banding and feldspar phenocrysts are common in this rock. No glassy base is now to be seen and most of the minerals are metamorphic. The formation shows a transition into the Montezuma schist.

Andesite.—This rock appears in Maryland and northern Virginia in many small areas. In all respects it resembles the Flattop schists, and each is probably metamorphosed from andesite.

Metarhyolite.—This rock cuts the Carolina gneiss, Cranberry granite, Blowing Rock gneiss, and apparently the Linville metadiabase and Flattop schist, in countless small beds, and it forms larger masses as a surface flow. The formation consists of dark-blue or gray metarhyolite in which flow banding and phenocrysts are common and lithophysæ and amygdules are often to be found. The phenocrysts consist of quartz and feldspar, and the groundmass is of the same minerals with a very fine grain. Much of the formation is metamorphosed to dark schists composed chiefly of fine quartz and muscovite. Large bodies of this formation are found in Maryland and southern Pennsylvania and have been described under the above heading and as aporhyolite. They are substantially the same as the metarhyolite described in North Carolina and occurring elsewhere in South Carolina, North Carolina, and eastern Virginia.

Correlation.—The enormous extent of the Paleozoic formations is well known. Single formations—for instance, the great Cambro-Ordovician limestone—reach continuously from Pennsylvania to Alabama. Recent investigations have shown an equally great extent for many of the igneous rocks. For example, the Roan gneiss—an altered basic igneous rock—extends with almost perfect continuity from northern Georgia nearly to Maryland. Masses of granite have as great a length. The Carolina gneiss has an even greater length and a breadth in North Carolina of more than 100 miles. The rocks of the soapstone group appear at short intervals with the same characteristics throughout the entire extent of the Appalachians. The pre-Cambrian lavas extend from southern Pennsylvania halfway through Virginia without a break, and farther south they form many areas 30 or 40 miles in length. In short, since practically every formation has a great linear extent, the conditions which produced the formations are of equal or greater extent.

The determinations of age for the various pre-Cambrian formations rest upon a very large basis of fact. The oldest rocks the age of which is determined by fossils are the lower Cambrian quartzites, outcropping along the northwestern front of the Appalachian Mountains. These are overlain by various calcareous formations of the Cambrian and Ordovician, which also contain fossils. At hundreds of localities between Pennsylvania and Georgia fragments of the igneous rocks are found in the Cambrian strata. In the Cambrian basal conglomerates nearly all of the igneous and metamorphic rocks are represented, but most of the fragments are the harder materials, including granite, quartz, and the jasper, epidote, and metarhyolite from the lavas. The fragments vary from arkose to rounded pebbles or to bowlders a foot or two in diameter. The interval of erosion between the Cambrian and pre-Cambrian rocks proved by these conglomerates might be long or short, so far as the sediments show. The internal evidence of the metamorphic and igneous rocks, however, is abundant.

The pre-Cambrian rocks are divisible into three great series, based upon the original nature of the rocks themselves and on the events through which they have passed. The first of these series consists of the Roan and Carolina gneisses, in which the structures due to metamorphism have largely obliterated the original textures. The second series consists of the various granites, massive, schistose, or gneissoid, such as the Cranberry, Beech, Max Patch, Blowing Rock, and Henderson. In these the original characters are evident throughout large masses and the acquired features of metamorphism are locally prominent. The third series consists of basic and acidic lavas. In places the original characters of these rocks are plain, while elsewhere they have been destroyed by metamorphism.

The gneisses of the first series are cut by the granites of the second series in countless places. The lavas of the third series cut through the granites and gneisses and spread out over their surfaces. Many great areas and separate basins are now known in the mountains and the Piedmont Plateau, and further work will doubtless reveal many more. They show an epoch marked by effusive rocks, in strong contrast with the preceding plutonic rocks.

The interval of time between the gneiss and granite series was enormous, as shown by differences in their acquired structures. The older gneisses received a strong schistosity through deformation. The schistose planes, the gneissoid banding, and the individual minerals have since been bent, wrinkled, and variously deformed. In places the secondary deformation has produced another schistosity, cutting across the earlier planes. The gneisses have, therefore, passed through two entirely distinct periods of metamorphism. The rocks of the granitoid series, on the other hand, show the results of only a single metamorphic period. The planes of shearing and schistosity and the accompanying flakes of parallel minerals now dip at angles which are similar over large areas. These were the results of a great force acting with considerable uniformity and thus producing uniform phenomena. The amount of metamorphism corresponds in degree to that produced in the group of gneisses by the first period of deformation. The period of deformation which rendered the granites schistose, however, is the second one which affected the gneisses. Thus it is seen that the series of gneisses is older than the series of granites by at least the time needed for a period of deformation and metamorphism. Regarding these as the expression of slowly accumulating strain in the earth's crust, the lapse of time must be considered very great.

The lavas of the third series as a rule overlie all of the other pre-Cambrian rocks. They were formed under fairly well-defined conditions, which include, in part, solidification at or near the surface of the earth and comparative freedom of horizontal flow. The igneous rocks of the granitoid series were solidified at great depths beneath the surface and under heavy loads. These conditions are entirely diverse from those which accompanied the production of the lavas. When, therefore, as is the rule, the lavas are seen to lie upon the deep-seated granites, it is evident that an enormous change in the conditions has taken place. This would result only from erosion of the surface, which slowly exposed the deeper granite masses. The interval of time implied by this is enormous. The total change in the character of the rocks, from plutonic to effusive, also shows a physical revolution of the first order. The inference is warranted, therefore, that the lavas are very much younger than the rocks of the granitoid series.

The application of the differences of age thus defined is far from simple. The lavas are separated from the Cambrian by a great unconformity. They form a totally different class of rocks, and all the conditions surrounding them were different from those which produced the Cambrian sediments. These differences justify the separation of the lavas into a different epoch, either Algonkian or Archean. In favor of Algonkian is the marked grouping of the areas of lava and of Cambrian sediments. In one region in North Carolina there is even a small contemporaneous lava flow near the base of the Cambrian. The lapse of time and the reversal of conditions between the lava series and the granitoid series are also sufficient to remove the granites into a period older than the lavas—that is, Archean. Between the granites and the gneisses, however, the lapse of time is equally great, and the gneisses might properly be put into a still older period, if there were such. Absence of that makes it necessary to call the gneisses also Archean, referring them to the earlier part of that era. It is clear that these assignments are strictly relative; still the differences between the three series are of the same order as, and of far greater magnitude than, the differences on which later geologic periods are founded. The broad facts are that the three series are separated, first, by great periods of deformation; second, by total reversal in all the conditions of formation, and, third, by visible unconformities.

SECTION 11. SUMMARY OF PRESENT KNOWLEDGE OF THE REGION.

In the southeastern part of the United States is a belt of holocrystalline rocks, in its broader parts more than 100 miles wide, which extends from Alabama continuously to Maryland, and with only a slight break into Pennsylvania, and finally into New Jersey as far as Trenton. The Piedmont Plateau is almost altogether occupied by these rocks, as are also the Blue Ridge and the Unaka Mountains.

The rocks of this belt comprise a great variety of gneisses, of granites, and of intermediate and basic igneous rocks, including both plutonic and volcanic. Also there are associated with these holocrystalline rocks extensive formations of sedimentary rocks which vary in their metamorphism from induration to complete recrystallization. In the earlier studies of this region practically all of the rocks of the region were placed with the pre-Cambrian, and were distributed between the Huronian and the Laurentian. A closer study has shown, just as in the New England region, that this complex mass of rocks includes those varying in age from Archean to Paleozoic.

When the first edition of this bulletin was published the stratigraphy of these crystalline rocks had not been worked out, and detailed mapping had been done in but limited areas. Since that time great progress has been made in the solution of the problems of the succession and structure of the region. Among those who have made important contributions to the knowledge of the region are Keith, Watson, Mathews, and Bascom. In the foregoing pages each of these geologists gives a summary of the state of knowledge of the districts respectively studied. Of these four, Keith has longest studied the region and has mapped the most extensive areas.

For the central part of the district Keith gives an admirable summary of the succession which he has worked out for a great area of the Piedmont Plateau, the Blue Ridge, and the Unakas. His studies lead him to conclude that the pre-Cambrian rocks are divisible into three great series. The oldest of these is an extensive set of gneisses, which are known as the Roan and Carolina gneisses. The latter is, at least in part, of sedimentary origin. Very much later than this series, and separated from it by at least one great period of deformation and metamorphism, are extensive granite masses, to which he has given the names Cranberry, Beech, Max Patch, Blowing Rock, and Henderson. These rocks intrude the first series in a most complex fashion, and they themselves had been metamorphosed by profound dynamic action before the appearance of the third series of rocks. This latest series consists of basic and acidic lavas. In most places these rocks have been so little metamorphosed that the original characters are plain, but in other places these characters have been destroyed by metamorphism. Keith thinks that the difference in age of each of these series is very great, but he emphasizes the great change in the nature of the formations indicated by the appearance of the third series, the volcanics. He refers the ancient gneisses and granites to the Archean, and places the lavas in the Algonkian to emphasize the dual classification, but without emphasis on specific correlation with Archean and Algonkian elsewhere.

Associated with the rocks which are certainly Archean or Algonkian are many belts of more or less metamorphosed sedimentary rocks, comprising conglomerates, quartzites, quartz schists, mica schists, slates, and limestones, the age of which is very difficult to determine. These belts of sediments vary in length and breadth from those which are comparatively narrow and extend a few miles to a great belt called the Ocoee group by Safford, which has a maximum width of 25 miles or more and which extends areally from North Carolina and Tennessee to Alabama. The great Ocoee belt comprises a large part of the great Unaka Mountains, but in its southwestward extension passes onto the relatively low lands of Alabama. At the northeastern end of the area the rocks are less altered than in the southwestern part. The Ocoee rocks in the unmetamorphosed district consist predominantly of conglomerates, quartzites, and slates with limestones, and in the metamorphosed districts these have been transformed to conglomerate schists, graywackes, quartz schists, mica schists, mica slates, and marbles.

Many of the minor belts of sediments occur upon the Piedmont Plateau in the Virginias, the Carolinas, and Georgia. In many places these belts are so extremely metamorphosed that they now show no evidence of fossils, if they once possessed them. Indeed, the metamorphism has destroyed all clastic characters. While it has not been proved, it is very probable that many of these belts belong to the same period as the great Ocoee group; thus the determination of the age of the Ocoee is of the greatest importance.

The age of the Ocoee group is a problem to which the attention of American geologists has been directed for more than a quarter of a century, and even at the present time its answer is not altogether clear. In the area where the Ocoee has been most closely studied, in North Carolina, Tennessee, and Georgia, Keith has reached the conclusion that the entire group is of Cambrian age. He divides his Cambrian, from the base up, into the Snowbird formation, the Hiwassee slate, the Cochran conglomerate, the Nichols slate, the Nebo quartzite, the Murray slate, the Hesse quartzite, above which is the Shady limestone. Above the Shady limestone follow other conformable formations of the Cambrian. The *Olenellus* fauna has been discovered as low as the Nichols slate. The formations which are certainly Cambrian are conformable with the lower formations of the Ocoee, and the upper part of the Ocoee is stratigraphically equivalent to the known Cambrian. The series as a whole, however, goes down several thousand feet below any discoverable fossils, and in this thickness contains at various places blue and gray limestones so little metamorphosed that one would expect to find fossils in them, but the closest search by Walcott and many others has failed to reveal a single trace of any organic form. The question arises as to what part of the Ocoee rocks is truly pre-*Olenellus* or Algonkian. About one-half seems to be of this age according to present knowledge. So far as the Ocoee is Algonkian the southern Appalachian is a province in which the unconformity between the Algonkian and the Cambrian generally found in the United States is represented by continuous deposition. Keith, who has done the most work in the district, believes that the whole group should be placed in the Cambrian because the rocks are all of the same kinds and form a continuous series, and that the absence of the usual unconformity is in favor of the Cambrian age. If this conclusion be correct it is probable that the greater number of belts of ancient sediments in the great central Piedmont area are of Paleozoic age.

The metamorphism of the rocks which have been denominated Ocoee increases southward and eastward from Tennessee. In North Carolina, Georgia, and Alabama these rocks are extremely metamorphosed. In one area of schists in Alabama which has always been called Ocoee E. A. Smith has recently found fossils that are probably Carboniferous and certainly not lower than Devonian, and this discovery suggests that so-called Ocoee belts of holocrystalline rocks upon the Piedmont Plateau in the southern part of the region, now completely metamorphosed and devoid of fossils, may be of post-Algonkian age. The Carboniferous beds, however, probably owe their present position to an extensive eastward overlap in Carboniferous time, and indicate nothing as to age of surrounding rocks, with which they are in marked unconformity.

Keith believes that this dual classification of the pre-Cambrian in the Piedmont area into Archean and Algonkian extends northward into Pennsylvania; that the Carolina gneiss is essentially continuous with the gneisses around Washington and Baltimore and possibly with the Fordham gneiss and the gneiss-limestone series of New Jersey, while the Algonkian volcanics are continuous with the volcanics of South Mountain, Pennsylvania. Farther to the north the volcanics are cut out and the Cambrian rests directly against what he regards as equivalent to his oldest pre-Cambrian. The correlation of the New Jersey rocks is so involved with that of the Adirondacks and of the Laurentian and Hastings districts that its assignment to the Archean would not be warranted on the basis of the classification made by Keith in the Piedmont area, which, as already indicated, is designed primarily to emphasize a dual division rather than correlation with the Archean and Algonkian elsewhere.

The work of Walcott, Mathews, Bascom, and Keith has led to the conclusion that large areas of semicrystalline rocks which were in early years supposed to be pre-Cambrian are Paleozoic. Thus the Chickies quartzite is Cambrian and the Shenandoah ("Chester Valley") limestone is Cambro-Ordovician. The only pre-Cambrian rocks in the Philadelphia district of Pennsylvania, according to Bascom, are the Baltimore gneiss and the Wissahickon mica gneiss with associated intrusives. Bascom and Mathews agree that the

Baltimore gneiss is pre-Cambrian, but there seems to be a difference of opinion in reference to the Wissahickon mica gneiss, Bascom holding that this formation is probably pre-Cambrian, while Mathews holds it to be Ordovician. The problem is a complicated one, but the weight of evidence at the present time seems to favor Bascom's view.

Bascom thinks that both the Wissahickon mica gneiss and the Baltimore gneiss are sedimentary in origin. If this conclusion be correct, it has a bearing upon the age of the metamorphic sedimentary rocks of the southern Piedmont. It has been intimated that these may be the equivalents of the Ocoee, and hence very likely of late Algonkian or Cambrian age; but if, in the northern Appalachian region, there are sedimentary rocks of pre-Cambrian age, this possibility can not be excluded for the metamorphic sediments of the southern Appalachians which have not been connected structurally with either the Cambrian or the pre-Cambrian rocks. On the other hand, the oldest Archean gneiss (Carolina) is shown by Keith to be in considerable part of sedimentary origin.

While in this summary the emphasis has been placed upon the results of the later workers, it would not be fair to pass by the pioneer work of the early men, and in this connection attention is particularly called to the early work done in Virginia by Rogers; that of Emmons in North Carolina; that of Safford in Tennessee, whose work barely reaches the pre-Cambrian rocks, and that of Lieber. The last in his earlier reports carefully refrained from generalizations based upon insufficient evidence, but patiently mapped the rocks lithologically in several counties, and thus gives serviceable information unmingled with theories of no value.

In the South, as in New England, occur formations which, by contained belts of conglomerates, are definitely proved to be of clastic origin, and these gradually pass into unmistakable crystalline schists. These transitions were clearly described and their meaning definitely pointed out by Emmons and Lieber, respectively, in 1856 and 1858.

More remarkable than this is the discovery of Emmons and Lieber that hornblende schists and other schists are metamorphosed eruptives. These rocks are said sometimes to be as thinly laminated as paper and are compared with slates, but their occurrence in dikes within the granites and their gradations into the ordinary massive forms demonstrate them to be later igneous rocks. These conclusions were not based upon petrographical work, but upon careful field study. The microscope in recent years has shown accurately the method of change; but that the change does occur from a massive eruptive rock to a thoroughly schistose one was proved beyond doubt by these men before 1860.

Emmons and Lieber further appreciated that the granite gneisses in their lithological affinities as well as by actual transitions belong with igneous granitic rocks rather than with the sedimentaries. Emmons also reached the same conclusion for the South which Emerson demonstrated many years later for the New England States—that there are two granites, one of which is more ancient than the clastics and the other intrusives within these. According to Emmons the ancient form is predominant, but occasionally granite has been projected through fissures, like other intrusive rocks.

The great discovery that regularly laminated rocks are produced by the metamorphism of eruptive rocks as well as from sedimentary rocks naturally carried the discoverer too far in the application of the principle. Emmons included in the metamorphic igneous rocks many mica schists, talcose slates, and limestones, for which he gave no evidence whatever. Lieber's discrimination between the metamorphic-igneous and metamorphic-sedimentary rocks was much more satisfactory. But Emmons's general statements as to the small value of lamination alone in rocks as evidence of origin, and his method of stratigraphic work in the crystalline rocks, can hardly be improved upon at the present day. Says this writer: Rocks of igneous origin are often massive, but also are frequently laminated, and laminated rocks are frequently called stratified, but this latter term should be restricted to the sedimentary rocks. The metamorphic rocks are excluded from the sedimentary classification because all rocks may become metamorphic, and a stratum metamorphic in one locality may not be metamorphic in another. The highest proof of the age of rocks is the order of superposition. When this method can be applied it is paramount, but paleontology may be used subject to proper principles.

The "Primitive" rocks from Emmons's point of view are all igneous; with aqueous rocks begins the "Azoic," the oldest sedimentaries, and above the "Azoic" are rocks which in the past have been regarded as azoic but are found to be fossiliferous; that is, they constitute the "Taconic" system. We have here a definite theory as to the order of development of the earth, the "Primitive" rocks being wholly pyrocrystalline, the "Azoic" stratified rocks being earlier than the dawn of life, and the "Taconic" rocks being the fossiliferous rocks earlier than the Potsdam.

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CHAPTER XII.

ISOLATED AREAS IN THE MISSISSIPPI VALLEY.

SECTION 1. WISCONSIN.

BARABOO.

SUMMARY OF LITERATURE.

SHUMARD,[1] in 1852, mentions the quartzite ranges of Sauk County, near Baraboo. The quartzites are surmounted by sandstone, and all are included in the great sandstone formation of southern Wisconsin.

PERCIVAL,[2] in 1856, describes the quartzite ridges of Baraboo and Portland. The rock is a hard granular quartz, which has more or less distinct lines of stratification, and resembles much a Primary granular quartz. In the Baraboo rock are layers more or less filled with rounded pebbles of quartz, resembling layers of the same kind in the lower sandstone, and oblique cross lines between the regular lines of stratification, which occurrences appear to connect it with the lower sandstone. The dip of these ranges is at a moderate angle to the north, and if the rock is formed from the sandstone by igneous action from beneath, the metamorphic change has not been accompanied by much disturbance of the strata. The localities in which Primary rocks are found are all within the limits of the lower sandstone, and most of them occur at the falls of the northern rivers. These rocks are mainly hornblendic and syenitic, although trap rocks resembling the intrusive traps of Connecticut are seen, but these are believed to be rather Primary greenstones. Descriptions are given of the rocks of Marquette and Waushara counties and of those of Black, Wisconsin, St. Croix, and other rivers. On Black River the rocks are syenite, greenstone, and chlorite slate, the latter accompanied by iron ores.

DANIELS,[3] in 1858, states that in the lower part of the Baraboo Valley are lofty ranges of hard quartzite which are the soft, crumbling Potsdam sandstone violently disturbed and changed.

HALL,[4] in 1862, concludes that the quartzite ranges of Baraboo and Necedah hold the same position relative to the Potsdam sandstone as the Huronian system of the Canadian Survey.

IRVING,[5] in 1872, maintains that the quartzites of Sauk County are unconformably below the Potsdam, because they are uptilted at a high angle, while the Potsdam is horizontal, and the horizontal sandstone abuts against the quartzite and holds fragments derived from it. These quartzites are either Laurentian or Huronian.

Eaton,[6] in 1872 and 1873, maps the quartzites of the Baraboo River. At Ableman's the highly tilted quartzites are flanked on both sides by horizontal sandstone and conglomerate, the latter having angular fragments of the quartzite of varying magnitudes. The overlying sandstone is exactly like that described by Irving at Devils Lake as containing Potsdam fossils. The sandstone is above horizontal limestone containing *Pleurotomaria*. The quartzite is, then, an old Azoic reef of tilted rocks, which suffered enormous erosion before it was washed by the waves of the Potsdam sea.

Murrish,[7] in 1873, describes the quartzite ranges of Baraboo as a metamorphic sandstone of Potsdam age.

Chamberlin,[8] in 1873, discusses cleavage and fissility phenomena in the softer layers of the Baraboo quartzite, and concludes that they are evidence of dynamic metamorphism of the series.

Chamberlin,[9] in 1873, discusses the post-Huronian history of the Baraboo quartzite ranges.

Irving,[10] in 1877, describes in some detail the geology of the Baraboo quartzite ranges, and concludes that the quartzites of the two ranges appear to be parts of a continuous series dipping to the north at angles as low as 15° on the south range and as high as 55° to 90° on the north range. Quartz porphyry beds on the north flank of the north range constitute the uppermost layers. Unconformable contacts of the Potsdam sandstone on the quartzite are figured and described.

Van Hise,[11] in 1893, considers the dynamic phenomena shown by the Baraboo quartzite ranges of central Wisconsin. These rocks, indurated by cementation, exhibit all stages from massive quartzite showing microscopically little evidence of interior movement, through a rock having in turn fracture and cleavage, to one which is apparently a crystalline schist, but in thin section still giving evidence of its fragmental origin. The schistosity produced by the movement of the layers over one another is parallel to the bedding. In places Reibungs breccias have developed. At one point minor faulting was noticed. These phenomena are more marked in the North Range than in the South Range, and thus bear in favor of Irving's explanation of the structure as a part of a single great fold in a set of layers 12,000 feet thick, the North Range being on the leg of the fold, and thus requiring greater readjustment of the beds than those on the South Range, which are near the crown of the anticline.

Weidman,[12] in 1895, describes the igneous rocks of the lower narrows of Baraboo River. These are in a belt from one-eighth to one-half mile wide, running for 4 miles in an east-west direction. Chemical and microscopical study shows this rock to be a quartz keratophyre. It is shown to be a volcanic rock by its flowage structure, broken crystals, and by volcanic breccias. The rock has a schistosity parallel to the bedding of the quartzite. The quartz keratophyre rests upon the topmost layer of quartzite, with a possible erosion interval. It has been folded with the quartzite, and, like that rock, rests unconformably below the undisturbed Cambrian.

WEIDMAN,[13] in 1904, describes and maps the Baraboo quartzite region of south-central Wisconsin.

A pre-Cambrian quartzite formation, having an estimated thickness of 3,000 to 5,000 feet, forms an east-west synclinorium about 20 miles long and ranging in width from 2 miles on the east to 10 or 12 miles on the west, resting on a basement of igneous rock consisting of granite, rhyolite, and diorite, in isolated and widely separated areas both north and south of the quartzite synclinorium. The largest area is one of rhyolite near the lower narrows of the Baraboo. The upturned north and south edges of the quartzite form, respectively, the North and South ranges of the Baraboo Bluffs, standing 700 to 800 feet above the surrounding country and above the intervening valley. In the valley are pre-Cambrian formations younger than and conformable with the quartzite. These are the Seeley slate, having an estimated thickness of 500 to 800 feet, and, above this, the Freedom formation, mainly dolomite, having a thickness estimated to be at least 800 feet, bearing iron-ore deposits in its lower horizon.

Flat-lying Paleozoic sediments, unconformably overlying the pre-Cambrian rocks, occupy the surrounding area and partly fill the valley. The Paleozoic rocks range from Upper Cambrian, Potsdam, in the valley bottom, to Lower Silurian, Trenton, on the upper portions of the quartzite ranges. The Potsdam sandstone has a thickness ranging from a few feet to a maximum of about 570 feet in the valley. Glacial drift is abundant over the quartzite ranges and in the valley in the eastern half of the district, but occurs only in the valleys in the western half.

The iron ore is mainly a Bessemer hematite, with soft and earthy, hard and black, and banded siliceous phases. A very small amount of hydrated hematite or limonite is also present. The rocks immediately associated with the ore, and into which the ore grades, are dolomite, cherty ferruginous dolomite, ferruginous chert, ferruginous slate, and ferruginous dolomite slate—in fact, all possible gradations and mixtures of the minerals dolomite, hematite, quartz, and such argillaceous minerals as kaolin and chlorite. In the ferruginous rocks associated with the iron ore the iron occurs as hematite and also in the form of carbonate, isomorphous with carbonates of calcium, magnesium, and manganese, in the proportions to constitute ferrodolomite and manganic ferrodolomite; as silicates combined with various proportions of alumina, lime, magnesia, and manganese; as chlorite and mica; and also very probably to a small extent as iron phosphate.

It is believed that the iron ore of the Baraboo district was originally a deposit of ferric hydrate, or limonite, formed in comparatively stagnant, shallow water, under conditions similar to those conditions existing where bog or lake ores are being formed to-day, and that through subsequent changes, long after the iron was deposited as limonite, while the formation was deeply buried below the surface and subjected to heat and pressure, the original limonite became to a large extent dehydrated and changed to hematite.

For literature on correlation of this district with the rocks of Lake Superior, see summaries of articles by Irving, Van Hise, and others in Chapter III, Lake Superior region, pages 108–252.

SUMMARY OF PRESENT KNOWLEDGE.

The Baraboo ranges constitute an outlier of pre-Cambrian rocks in the Paleozoic area of south-central Wisconsin. The crystalline rocks are mainly quartzite, and until recently it was not known that other rocks were present in abundance. It was formerly supposed also that the quartzite constituted the remnant of the north limb of a great anticline. It is now known, from the work of Weidman, that the quartzite is in the form of a syncline, the north and south edges of which form respectively the North and South Baraboo ranges, and that within the intervening low synclinal area, beneath a considerable thickness of Cambrian sediments, there are other sedimentary rocks conformably above the quartzite. These are the Seeley slate, 500 to 800 feet thick, and above this the Freedom dolomite, 800 feet thick, the lower portion of which is ferruginous and shows concentrations of iron ore in commercial quantities and grades. The quartzite is found to rest unconformably upon an igneous basement which appears both north and south of the ranges. This basement consists of granites and of acidic volcanics, principally metarhyolite, showing brecciated, spherulitic, perlitic, and fluxion structures. It was formerly supposed that these rocks overlay the quartzite.

The crystalline series lie unconformably below the upper Cambrian of this area, but their precise ages are not known. Hall and Irving referred it to the Huronian at an early date, and Irving, followed by Van Hise, later concluded it to be upper Huronian on the basis of its general lithological character. With the recent discovery of new formations associated with the quartzite, the sedimentary series shows closer resemblance to the middle Huronian of the Marquette district of Michigan than to any other group, the Baraboo quartzite corresponding to the Ajibik quartzite, the Seeley slate to the Siamo slate, and the Freedom dolomite with heavily ferruginous horizon at its base to the iron-bearing Negaunee formation, which is known to have resulted from the alteration of iron carbonate. The sedimentary series will here be called Huronian and the basement complex will be called Archean.

WATERLOO, PORTLAND, AND LAKE MILLS.

SUMMARY OF LITERATURE.

PERCIVAL, in 1856, discusses the geology of this district. See summary under Baraboo, page 717.

IRVING,[14] in 1873, maintains the pre-Potsdam age of the Portland quartzite on the same ground as the pre-Potsdam age of the Baraboo ranges. There is a close similarity between the Baraboo and Portland quartzites and the rocks in northern Wisconsin and Michigan which are now regarded as Huronian.

CHAMBERLIN, in 1877, describes the geology of this district. See summary under Fox River Valley, page 722.

BUELL,[15] in 1892, describes and maps the Waterloo quartzite areas. These are a series of detached outcrops resting unconformably under the Lower Silurian of southern Wisconsin. Within the quartzite are occasional layers of conglomerate. The different outcrops are apparently parts of a synclinal fold. As a result of the shearing much of the quartzite has been crushed, and sericite has developed.

For literature on correlation of this district with the rocks of Lake Superior, see summaries of articles by Irving, Van Hise, and others in Chapter III, Lake Superior region, pages 108–252.

WARNER,[16] in 1904, maps and describes the quartzite of the Waterloo, Portland, and Lake Mills areas, collectively referred to as the Waterloo quartzite. The quartzite outcrops have distribution and structure such as to suggest that they represent parts of the edge of a great eastward-pitching syncline of quartzite. The quartzite is almost identical lithologically with the Baraboo quartzite, and its synclinal axis is along the line of the axis of the Baraboo syncline. There is little reason to doubt that the Baraboo and Waterloo quartzites are of the same age. If this be the case, one would expect to find slate and ferruginous dolomite formations within the Waterloo quartzite syncline, as in the Baraboo syncline. On this basis Warner has mapped the theoretical distribution of such formations beneath the Paleozoic rocks. Like the Baraboo quartzite, the Waterloo quartzite is referred to the Huronian, and its similarity with the Middle Huronian series is emphasized. Well drilling outside of the Waterloo syncline shows the presence of a granite basement.

FOX RIVER VALLEY.

SUMMARY OF LITERATURE.

Irving,[17] in 1877, describes the quartz porphyry at Marcellon, Observatory Hill, Moundville, Pine Bluff, Marquette, and Berlin, and the granite at Montello, in Marquette County, and at Marion, in Washara County. All are assigned to the Archean, using this term to cover all pre-Silurian rocks. From emphasis placed on the bedding it is apparent that the quartz porphyries are considered to be sedimentary.

Chamberlin,[18] in 1877, describes the Archean rocks which in the eastern part of Wisconsin protrude through but are not intrusive in the Paleozoic formations. These are the Mukwa granite, the Berlin porphyry, the Pine Bluff quartz porphyry, the Marquette quartz porphyry, and the quartzites of Portland and Waterloo. The porphyries are found to have obscure but distinct bedding. The metamorphosed quartzites show ripple marks and contain conglomeratic layers. The Potsdam sandstone and Lower Magnesian limestone rest in a horizontal position against, and contain fragments from, the crystalline rocks. The quartzites are regarded as originally sandstones and conglomerates which were metamorphosed before the neighboring horizontal rocks were deposited, and were tilted and eroded before the stratified rocks were deposited. These quartzites are regarded as a portion of the Baraboo quartzite series.

Pretts,[19] in 1895, describes and maps the rocks of Marquette on Fox River. They are acidic igneous rocks with volcanic textures, cut by basic dikes.

Leith and Hobbs,[20] in 1897, 1898, and 1899, describe and map the rocks of Marcellon, Observatory Hill, Taylors Hill, Moundville, Montello, and Marquette. The rocks are principally metarhyolites, some of them aporhyolites, showing a great variety of surface volcanic textures and cut by basic dikes. At Montello is a porphyritic granite. From their similarity to rhyolites on the north flank of the Baraboo Range, mapped by Weidman as Keweenawan, they are tentatively asigned to the Keweenawan.

Weidman,[21] in 1898, describes the pre-Cambrian igneous rocks of the Utley, Berlin, and Waushara areas in the Fox River valley of Wisconsin. They range from volcanic flows to masses of deep-seated origin, with corresponding textures. The rock of the Utley area is a metarhyolite, at Berlin a rhyolite gneiss, and in the Waushara area a granite. Analyses of the rocks of the three areas show a close similarity in chemical composition, and it is believed that the rocks represent phases of a single parent magma. The rocks have been metamorphosed to different degrees, and the results of the metamorphism, particularly of the feldspars, are described in detail.

The crystalline rocks are unconformably overlain by flat-lying Potsdam and Ordovician sediments. From their similarity in composition to the Baraboo volcanics, which are considered to be of Keweenawan age, it is believed that they belong to the same province, and are therefore of Keweenawan age.

For literature on correlation of this district with the rocks of Lake Superior, see summaries of articles by Irving, Van Hise, and others in Chapter III, Lake Superior region, pages 108–252.

SUMMARY OF PRESENT KNOWLEDGE.

In Fox River valley are several small isolated outcrops of pre-Cambrian crystalline rocks projecting through the Paleozoic sediments. These are at Berlin, Utley, Waushara, Marquette, Montello, Observatory Hill, Marcellon, and Endeavor. The rocks are mainly acidic extrusives, metarhyolites, showing gradations into rocks of more deep-seated origin, rhyolite gneiss, quartz porphyry, and granite, all of them cut by basic dikes. The characteristic feature in the metarhyolites is the presence of abundant and well-preserved surface volcanic textures, such as fluxion, perlitic, spherulitic, and brecciated textures. The lithological similarities of the rocks, the presence of the surface textures, and their composition as shown by analysis, indicate clearly the consanguinity of the igneous rocks of these areas with one another and with certain of the igneous rocks on the north and south sides of the Baraboo Range. In the Baraboo district these rocks have been found by Weidman to be unconformably below the sedimentary rocks, and hence the volcanics of Fox River may be supposed to be pre-Huronian. Up to 1903 all had been tentatively referred to the Keweenawan, because the Baraboo igneous rocks had been supposed to lie on the quartzite.

NECEDAH, NORTH BLUFF, AND BLACK RIVER.

SUMMARY OF LITERATURE.

Percival, in 1856, discusses the geology of this district. See summary under Baraboo, page 717.

Daniels,[22] in 1858, describes the iron ores of Black River Falls as associated with the chloritic and micaceous slates of the Azoic system. Syenite is also found adjacent. The fossiliferous horizontal sandstone rests upon the upturned edges of the Azoic slates, and at the base of it is a brecciated conglomerate consisting of sand, ore, and slate. In the lower part of the Baraboo Valley are lofty ranges of hard quartzite which are the soft, crumbling Potsdam sandstone violently disturbed and changed.

Hall,[23] in 1862, concludes that the quartzite ranges of Baraboo and Necedah hold the same position relative to the Potsdam sandstone as the Huronian system of the Canadian Survey.

Murrish,[24] in 1873, describes granitic and hornblendic Azoic and plutonic rocks on the Black and Yellow rivers. At Black River Falls are knobs of magnetic ore in a series of elongated knobs or mounds, associated with quartz and micaceous slate. At Grand Rapids, on Wisconsin River, are found Azoic rocks similar to those on Black River. A quartzite mound at Necedah occupies a geological position similar to the iron ores at Black River Falls.

Irving,[25] in 1877, describes the quartzite at Necedah. The structure is not apparent. It is mapped as Archean.

Hancock,[26] in 1901, maps and describes the iron formation and adjacent rocks along the Black River valley northward from Black River Falls. They are observed in unconformable contact with overlying Paleozoic rocks.

For literature on correlation of this district with the rocks of Lake Superior see summaries of articles by Irving, Van Hise, and others in Chapter III, Lake Superior region, pages 108–252.

SUMMARY OF PRESENT KNOWLEDGE.

At Necedah, in Juneau County, and at North Bluff, in Wood County, are quartzite exposures projecting through the Cambrian.

Drilling at Necedah has disclosed the presence of granite, probably intrusive into quartzite. The quartzite is highly metamorphosed. The age of this quartzite is not known, but its lithological similarity is with the lower Huronian.

In the Black River valley northward from Black River Falls are exposures of gneiss, granite, hornblende schist, magnesian schist, and ferruginous quartz schist, mapped by Irving in 1873, and subsequently by Hancock in 1901. The relation of these rocks to one another is not definitely known. All are pre-Cambrian.

SECTION 2. SIOUX QUARTZITE OF CONTIGUOUS PORTIONS OF MINNESOTA, SOUTH DAKOTA, AND IOWA.

SUMMARY OF LITERATURE.

Hayden,[27] in 1867, in his sketch of the geology of northeastern Dakota, describes quartzites along James River, Vermilion River, and at Sioux Falls. These quartzites are sometimes conglomeratic. On James River the lines of stratification are nearly obliterated, but the rock appears to be metamorphic. The pipestone bed on Pipestone Creek is associated with the quartzites already mentioned, and this rock is undoubtedly of the same age. At Sioux Falls, while no well-defined fossils were discovered, upon the outer surfaces of the rocks are rounded outlines of what appear to be organic remains, but the peculiar character of the quartzite points toward the Azoic series. The formation is tentatively referred to the Super-Carboniferous, Triassic, or downward extension of the Cretaceous; but Hall's opinion that this rock is Huronian is entitled to great weight.

WHITE, in 1870, describes the quartzite of Iowa, Minnesota, and Dakota. See summary under Lake Superior region, Chapter III, section 3, Minnesota, page 197.

WINCHELL (N. H.),[28] in 1885, finds in the red quartzite at Pipestone two fossils, *Lingula calumet* and *Paradoxides barberi*, which are taken as indicative that this formation, as well as the Sioux quartzite of Iowa and Dakota, the Baraboo quartzites of Wisconsin, the quartzites of southwestern Minnesota, and the associated red gneisses, felsites, and felsite porphyries, are all Primordial.

UPHAM,[29] in 1885, gives descriptions of the quartzites of Minnehaha County, Dak. These are not infrequently ripple marked and conglomeratic; they are like the quartzites of Pipestone County in Minnesota, and, like them, are placed in the Potsdam.

BEYER,[30] in 1895, describes spotted slates associated with the Sioux quartzite series in the northeast corner of Minnehaha County, S. Dak. The quartzite here grades up into reddish slate, which in lithological character corresponds to the quartz slate in the Penokee series of Michigan and Wisconsin, described by Irving and Van Hise.

KEYES,[31] in 1895, gives the result of an examination of the Sioux quartzite. At several points in the bedding planes of the quartzite were seen impressions which so much resembled those of lamellibranchs of the *Cardium* and *Cytherea* types, that, notwithstanding strong preconceived notions of the ancient age of the Sioux rocks, faith in their old age was very much shaken. It is concluded that the Sioux formation should be considered as pre-Cambrian until indisputable evidence to the contrary is produced, but that there now exist certain doubts concerning the accuracy of this view.

NORTON,[32] in 1897, in a description of the artesian wells of Iowa, discusses the attitude of the Algonkian floor. In the northwestern part of the State the Algonkian outcrops as the Sioux quartzite. From here it sinks rapidly to the south and east, and is discovered near the area of its outcrop only by the steep wells at Sioux City, Hull, and Le Mars. In the east-central part of Iowa is a slight elevation of the Algonkian floor, disclosed by the artesian well at Cedar Rapids. In Wisconsin the Algonkian outcrops as the Baraboo quartzite, a rock similar to the Sioux quartzite. From this outcrop the Algonkian sinks gently to the southwest, as it is reached by the drill at Lansing, Iowa. At no other place in Iowa has the drill gone deep enough to reach the crystalline rocks.

Beyer,[33] in 1897, maps and describes the part of the Sioux quartzite formation exposed northeast of Sioux Falls in secs. 10, 11, 14, 15, 22, and 23, T. 102 N., R. 48 W., South Dakota. The quartzite dips from 3° to 7° SW. An accurate estimate of the thickness may not be given, but 1,500 feet is a liberal one.

Slate is exposed in the area in isolated outcrops, but never in contact with the quartzite. In composition it corresponds very closely to the quartz slate of Irving and Van Hise.[a] Intruding the slate are diabase dikes, which have followed the bedding.

The relations of the slates and quartzites can not here be ascertained. However, from the relations of the two outside of the area it is believed that the slates are the upward continuation of the quartzite, and that they have been removed in large part.

The age of the Sioux quartzite is believed to be pre-Cretaceous. Its reference to the Huronian may be supported by the following facts: The lithological characters of the quartzite are identical with those of the Baraboo quartzite in Wisconsin, which has been referred by Irving and Van Hise to the Huronian. The diabase intruding the slate, supposed to be the upward continuation of the quartzite, is strikingly similar to intrusives which are peculiar to the Huronian in the Lake Superior region.

Wilder,[34] in 1899, describes and maps the Sioux quartzites and quartz porphyries of Lyon County, Iowa. No points concerning stratigraphy or age have been added to those already given by other writers.

Todd,[35] in 1904, reports the presence of gabbro within one-half mile of the Sioux quartzite of South Dakota. He believes it to be intrusive into the quartzite, although no contacts are found.

Darton,[36] in 1905, in connection with the study of the artesian wells of eastern South Dakota, maps the configuration of the bed rock. The Sioux quartzite ridge of the southeastern part of the State is found to extend westward beneath the Paleozoic rocks nearly to Missouri River. On the north side a few deep wells are bottomed in granite. A few scattering records of quartzite, some of them doubtful, also appear both to the north and to the south of this ridge.

For literature on correlation of this district with the rocks of Lake Superior see summaries of articles by Irving, Van Hise, and others in Chapter III, Lake Superior region, pages 108–252.

SUMMARY OF PRESENT KNOWLEDGE.

In a small area covering the contiguous corners of Minnesota, Iowa, and South Dakota is the Sioux quartzite, consisting mainly of reddish vitreous quartzite but having associated with it quartz slate

[a] Van Hise, C. R., and Irving, R. D., The Penokee iron-bearing series: Tenth Ann. Rept. U. S. Geol. Survey, 1890, pp. 370 et seq.

similar to the quartz slate of the Penokee-Gogebic district. The supposed fossil remains reported by N. H. Winchell have been examined by Walcott and thought not to be organic. The series is surrounded by Cretaceous rocks and is unconformably overlain by them. The structural relations indicate only that the quartzite is pre-Cretaceous, but because of its lithology and its proximity to the Lake Superior region it has uniformly been referred to the Huronian. Previously the rocks have been referred to the upper Huronian because of the existence in conglomeratic phases of chert and jasper fragments presumably derived from an underlying Huronian group. It is now known that these fragments may have been equally well derived from the Archean, and thus their presence gives no evidence of the age of the rocks.

SECTION 3. BLACK HILLS OF SOUTH DAKOTA.

SUMMARY OF LITERATURE.

Hayden,[37] in 1862, states that the nucleus of the Black Hills consists of red feldspathic granites, with stratified metamorphic Azoic slates and schists, upon which rests unconformably, forming a zone around the ellipsoidal nucleus, a series of reddish ferruginous sandstones, which by their organic remains are shown to belong to the Potsdam. In the Potsdam are found as pebbles the different varieties of the changed rocks beneath.

Hayden,[38] in 1863, describes the Black Hills as an outlier of the Rocky Mountains. They are formed of a granite nucleus surrounded by a series of Azoic highly metamorphosed strata standing vertical, and comprise slates, gneiss, syenite, and quartzose and calcareous rocks.

Hayden,[39] in 1872, describes the Black Hills as being the most complete illustration of an anticline not complicated by any other influences that he has found in the West. The nucleus is a massive feldspathic granite with a series of gneissic beds outside of it, which incline in every direction from this nucleus in a sort of narrow oval quaquaversal, and include all the unchanged beds known in this portion of the West from the Potsdam sandstones to the top of the Tertiary lignites.

Winchell,[40] in 1875, in a report on the Black Hills, describes a series of mica slates and mica schists with intercalated beds of quartz, below the Primordial sandstones and quartzites. These rocks often stand nearly vertical. In the neighborhood of the granite areas they are interstratified with beds of true granite, and with this granite is found tourmaline. The granite area is near the southern part of the hills, and of this Harney Peak may be taken as a center.

Newton,[41] in 1880, gives a systematic account of the Black Hills of Dakota. The Black Hills are a geological area which is admirably circumscribed. They consist of a nucleal area of metamorphic slates and schists containing masses of granite, about which is an inward-facing unconformable escarpment of Potsdam sandstone and Carboniferous limestone which dip away on all sides from the axis of the hills. The Archean rocks as a whole occupy an area of about 850 square miles, being about 60 miles long and 25 miles wide at its maximum. At numerous points within the hills are centers of volcanic eruption which was probably contemporaneous with the elevation of the mountains. It is impossible to estimate with any degree of accuracy the thickness of the Archean schists, as they are highly inclined and distorted, and in their present metamorphosed and denuded condition it can not be determined whether they are the remnants of several great folds or whether they are the broken strata of one vast fold, though the latter seems to be the more probable structure; in which case the total thickness of the Archean strata must be more than 100,000 feet, about 25 miles. The examination showed no evidence of the duplication of any parts of the Archean strata, and it is presumed, if a repeated folding has taken place, that it did not occur within the area exposed in the hills.

The Archean sedimentaries are divided into two groups, schists and slates. The schists include quartzose, garnetiferous, ferruginous, and micaceous varieties, together with some gneiss, chloritic, talcose, and hornblendic schists, and quartzite. The schists are occasionally staurolitic. The whole series is coarse in texture, highly crystalline, and contains seams or veins of quartz conformable with the stratification and having a lenticular form. The slates are distinguished from the schists mainly by their fine and compact texture, although, as shown by Caswell, their ultimate mineral composition is similar. They are mainly micaceous clay slate, siliceous slate, and quartzite, which are sometimes associated with specular oxide of iron. On Box Elder Creek is a ridge 400 feet in height, which is a vast deposit of siliceous hematite resembling the siliceous hematites of the Lake Superior region. The quartzites of the two classes are similar. The mica schist passes into chlorite schist, siliceous schist, and quartzite. The schists of the southern part of the hills are associated with an area of highly feldspathic granite which culminates in the region of Harney Peak. On the outskirts of this district are many smaller masses of granite. So far as the structure was made out, each of the bodies has a lenticular shape and is intercalated among the strata of the schists. No granite is found associated with the slate. The general strike of the rocks is northwest-southeast. The topography shows that there is a series of ridges in this direction which mark the position of the particularly hard layers, such as quartzites. The schists are found in the western and southwestern parts of the area and the slates in the eastern and northeastern.

Between these two groups Jenney noted a distinct discordance of dip on Castle Creek, but in the absence of corroborative observations the unconformity of the two series can not be insisted upon. The division of the system into two series is, then, based on lithological differences purely and is warranted on this ground. The lithological difference is, however, more a mineralogical than a chemical one, being probably due to difference in metamorphism. The apparent discordance discovered by Jenney and this lithological difference give strong support to the view that the slate and schist periods were separated by an interval of time during which there was erosion and metamorphism of the lower series. The granite is coarsely crystalline. It is concluded that, because of the great amount of feldspar in the granite, because pieces of schist are inclosed in it without any transition, because the granite masses in the schist have a long lenticular shape, because of the coarseness and evenly granular character of the granite, and because there is never any transition between the schist and granite, the latter is an eruptive rock in the schists. That the Archean rocks were upturned and metamorphosed before Potsdam time is shown by the fact that the basement conglomerate of the Cambrian contains fragments of slate, schist, and granite precisely like the underlying rocks.

Since the lithological character of the Black Hills Archean is the only means of judging their affinities it should have some weight. The eastern slate division bearing the lean ores is very similar to the Huronian rocks of the south shore of Lake Superior and Canada. The western schist series containing granite masses differs from the Huronian and from the Laurentian in that gneiss, the most characteristic rock of the latter, is nearly lacking, so that no correlations are made further than to call the slate series newer Archean and the schist series older Archean.

Blake,[42] in 1885, on account of the presence of staurolite in the Black Hills schists, places these formations as the probable equivalent of the Coos group of Hitchcock in New Hampshire, and it is said that there is sufficient breadth of formation to include all the rocks from the Huronian to the Coos.

Crosby,[43] in 1888, finds that the two groups of Archean as mapped by Newton are rather sharply defined from each other. It is said that in the eastern series of slates are pebbles which have been almost certainly derived from the harder rocks of the western series. The strike of the schists is found to curve around the granitic and gneissic area, and the normal dip of the strata is away from this nucleal granitic mass. A conglomerate is associated with the quartzite of the eastern slate area, the pebbles of which have suffered extensive deformation by compression. The granitic rocks of the schist area do not penetrate the slates of the newer series, although this is not devoid of eruptive rocks. The newer series of slates is correlated with the Taconian of western New England. The conclusion is reached that the granite, instead of being of eruptive origin, is pegmatitic.

CARPENTER,[44] in 1888, states that the unconformity supposed to exist by Newton between the eastern slate and the western schist series is supported by an observation upon Spring Creek east of Hill City. A huge dike of igneous rock, a thousand feet broad in places, is described as passing through the entire length of the eastern series.

VAN HISE,[45] in 1890, finds that the prominent structures of the Black Hills, which have heretofore been taken as bedding, are secondary structures. As evidence of this is the fact that alternating bands of sediments of different characters are seen to cut across the prominent lamination. Sometimes these belts are conglomeratic and the pebbles are deformed by pressure. The longer axes of the pebbles are parallel to the slaty or schistose structure, but the belts as a whole cut across this structure. The fact, cited by Newton, that there are persistent belts of quartzite parallel with each other, also indicates duplication by folding. The thickness of the Archean is, then, unknown, instead of being more than 100,000, as supposed by Newton. The crystalline schists are in a broad zone about the granite area, striking parallel to it and dipping away from it, and in the northern hills there are great quantities of later eruptives. Granite is found in the slate area as mapped by Newton.

A study of the boundary between the slate and the schist series leads to the conclusion that there is a gradation from the slates to the schists rather than an abrupt change. The foliation of the schists about the granite is secondary and is caused by the contact and dynamic metamorphism due to the intrusion of the granitic rock. The effect has extended for several miles from the main granite area. The normal foliation of the slates and schists is north-south, and this was produced by folding earlier than the intrusion of the granite. About the granite area both sedimentation and this earlier foliation were destroyed and a more prominent foliation was produced. Also, in the northern part of the slates, about Deadwood, is a considerable area which is now as crystalline as the schist area of the south. This is taken to be due to the abundant later intrusives here found. We thus have in this region evidence of an original bedding which is nearly obliterated by a prominent slaty cleavage, and both of these have been wholly destroyed for considerable areas by a newer and more prominent schistose structure. The slates and schists can not, then, be divided into two series with the surface distribution and upon the lithological differences given by Newton.

The mica slates, mica schists, and mica gneisses are found to be clastic rocks, the processes of change from their original clastic condition to their present crystalline one being traced out. Associated with the clastic rocks are other green crystalline schists, which are metamorphosed basic eruptives that were probably intruded before the earlier folding of the slates. Corroborating Newton's conclusion, it is said that the Black Hills rocks exhibit a remarkable lithological analogy to certain of the iron-bearing series of the Lake Superior region, which in the past have been included under the term Huronian. While this correlation is not beyond doubt, there is no question that these series in common belong to the Algonkian.

Todd,[46] in 1895, maps and gives a general description of the geology of South Dakota. Archean [a] rocks are present in the Black Hills, near Sioux Falls, and near Bigstone Lake in the eastern part of the State.

In the Black Hills the Archean rocks are slates and schists, intruded by granite. The metamorphic effects in the slates and schists become more pronounced as the contact with the granite is approached. Following Van Hise, it is believed that their metamorphism was largely brought about by the intrusion of the granite. The thickness of the slates and schists is from 10,000 to 100,000 feet. In age they are believed to correspond to the Lower Huronian of the Lake Superior region. The granites, while younger than the slates and schists, are still pre-Cambrian.

The Sioux quartzite is similar to the quartzite of Baraboo and the Chippewa Valley, of Wisconsin, and, following Irving and Van Hise, it is believed to be of Upper Huronian age.

Near Bigstone Lake are exposures of granites, probably of Laurentian age.

All the Archean rocks are overlain unconformably by Cambrian rocks, which in general dip away from the Archean exposures.

Todd,[47] in 1898, reports on a section across the Black Hills from Rapid City westward. The alternating slate and quartzite beds of the Algonkian were found to be folded in a most intricate fashion. A number of the folds were worked out. In most cases the lamination and stratification seem to correspond in direction.

Frazer,[48] in 1898, sketches the geology of an area in the vicinity of Galena, in the northern Black Hills of South Dakota. Mica schists, thought to be upper members of the Archean, are found striking northeast-southwest and dipping at angles of 38° to 85°. They are generally micaceous and coarse grained, but vary greatly, sometimes passing into nacrite schist or hydromica schist, and sometimes, though more rarely, assuming a heavily bedded character reminding one of gneiss.

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[a] Archean is used to designate the pre-Cambrian.

IRVING,[49] in 1899, gives a detailed description of the geology of an area in the northern Black Hills of South Dakota. The Algonkian rocks consist of quartzites, slates, phyllites, and schists, all of sedimentary origin. No new point is added concerning the stratigraphy of the pre-Cambrian rocks.

JAGGAR,[50] in 1901, in connection with the discussion of the laccoliths of the northern Black Hills, incidentally refers to the structure of the Algonkian. Its lamination abuts abruptly against the hard basal Cambrian quartzite or the conglomerate, and has a fairly uniform strike of north-northwest. The Algonkian surface is seen to be warped.

JAGGAR,[51] in 1904, describes the general geology of the Black Hills and gives particular attention to the dynamics of the later intrusions of the northern part of the uplift. The southern portion was occupied by massive ancient pegmatite granites, themselves pre-Cambrian intrusives in Algonkian strata. Probably they acted as a rigid cementing and hardening agent, to prevent fracturing, in the southern schists; the northern, less indurated phyllites cracked and faulted more readily to permit the younger intrusives to rise from the depths. The northern exposed schist areas contain many hundred dikes and some stocks; these must have induced movements of horizontal extension in the schist, and such movements are attested by bedding-plane faults at the base of the Cambrian. The dikes have a common trend, and dip parallel with the schistosity. The dip gave them a tendency to spread in the Cambrian in one direction more readily than in another.

Two illustrative sections are given. North of the Homestake mine, on Deadwood Creek near Central, Algonkian rocks appear as follows, from west to east: Graphitic schist, mica schist, heavy ferruginous black schist with quartzite bands cut by irregular white quartz bodies which form a distinct zone, ferruginous schist, mica schist, all dipping toward the east; mica schist with thin sandstone stringers, dipping to the west. This sudden change of dip just opposite the De Smet and Homestake ore bodies is significant, and suggests that perhaps the great ore body may fill a synclinal saddle pitching to the southeast.

A section from north-northwest to south-southeast along the ridge northeast of the Clover Leaf mine is: Garnetiferous mica schist, graphitic schist, ferruginous quartzite, amphibolite, mica schist, white quartz, mica schist, amphibolite, quartzite, and amphibolite.

SUMMARY OF PRESENT KNOWLEDGE.

In the Black Hills is a great series of Algonkian rocks, composed chiefly of mica slates, with quartzites, schist conglomerates, and ferruginous chert, and smaller areas of mica schists and mica gneisses of unknown but probably great thickness. They extend over an oval area 60 miles long and 20 miles broad. These rocks are folded into close rolls having north-south axial planes, and are cut by a regional cleavage which is usually nearly vertical. The ordinary metamorphism is believed to be largely due to the folding. The sedimentary rocks are cut by various masses of intrusive granite and basic rocks of Algonkian age, and also by later eruptives. The largest granite mass is 8 or 10 miles long and nearly as broad. A number of other masses are of considerable size. Adjacent to these batholiths occur numerous large dikes of granite. In passing away from them dikes become less abundant and smaller in size, until they finally disappear. Close to the large granite masses the dikes have typical granitic structures; farther away they grade into pegmatitic rocks, and these, by a lessening of the feldspar, grade into ordinary quartz veins, showing at places a banded structure. There can be little doubt that the dikes are dependent upon the batholiths of granite. There is equally little doubt that the quartz veins are water impregnations. Between the two there appear to be gradations. About the great batholiths the sedimentary rocks are thoroughly crystalline, being transformed to mica schists and mica gneisses, with secondary structures parallel to the intrusive masses, the original structures being destroyed. In places the mica schists and mica gneisses are thoroughly pegmatized. The zonal belt of schist passes by gradation into the ordinary cleaved slate of the district.

Resting unconformably upon the deeply denuded edges of the Algonkian schists and granite is the nearly horizontal middle Cambrian sandstone.

In degree of folding, character, and mineral composition the sedimentary rocks resemble a part of the upper Huronian of the Lake Superior region. The recent extension by drilling of the iron-bearing upper Huronian rocks of the Cuyuna district of Minnesota westward into North Dakota suggests a possible connection with the schists of the Black Hills, which are lithologically and structually similar to the rocks of the Cuyuna district.

The Black Hills afford one of the best instances known of the metamorphic effect of great intrusive masses of granite.

SECTION 4. MISSOURI.

SUMMARY OF LITERATURE.

King (H.),[52] in 1851, states that the Primitive formation is met with near a point about 70 miles south of St. Louis and 30 miles west of the Mississippi. It consists chiefly of granite, syenite, and porphyry, and rises in conelike elevations or detached ridges to the height often of 1,000 or 1,200 feet above the level of the Mississippi River. The sides and valleys are in many places covered with sandstone and limestone in such quiet relationship as to show that their deposition has taken place since the Primitive rocks assumed the form they now have. It is not at all unusual to find portions or fragments of the older rocks embedded in those that are stratified. This occurs both in the lowest magnesian limestone and in the overlying sandstone. The Primitive rock is broken through by greenstone dikes which reach the surface of this rock yet never penetrate the overlying sandstone. At Iron Mountain is a layer of specular oxide of iron, below which at one place is a stratified rock which may have been a modified granite. The iron-ore deposit is often in the form of pebbles in various sizes up to a foot in diameter. In the interstices of these pebbles is a reddish-brown clay. The bed of iron in the thickest point opened is 20 feet thick. At the summit of Pilot Knob is an immense mass of solid ore which is associated with porphyry and appears to pass by insensible gradations into that rock.

WHITNEY,[53] in 1854, describes Iron Mountain and Pilot Knob as localities in which are found eruptive ores of Azoic age. Iron Mountain is a flattened dome-shaped elevation, composed of feldspathic porphyry. The surface of the mound is covered with loose pieces of ore, which is in some places in a layer at least 15 feet thick. Pilot Knob is mainly composed of dark siliceous rock, distinctly bedded, dipping to the south at an angle of 25° or 30°. For about two-thirds of its height of 650 feet quartz rocks predominate; above that iron is found in heavy beds alternating with siliceous matter.

SWALLOW,[54] in 1855, describes the granite, greenstone, and porphyry of Missouri as igneous rocks. Red feldspathic granite, sparingly micaceous, occurs in sec. 15, T. 34 N., R. 3 E. Nearly all of the hills and ridges in the neighborhood of Iron Mountain and Pilot Knob are wholly or in part formed of compact reddish-purple feldspathic porphyry. The porphyry is one of the oldest rocks of the State, but no opportunity occurred for determining whether it is older than the granite, although there is no doubt that it is older than the greenstone, as the latter rock is said to occur in dikes in the porphyry. The porphyry is older than the stratified rocks of the region, because they are found resting upon knobs and ridges of porphyry in a position so nearly horizontal as to preclude the idea that they were deposited before the upheaval of the principal masses which form the hills. Whether the slates interstratified with the iron near the top of Pilot Knob are older is not easily determined.

SWALLOW,[55] in 1859, states that in one locality in Laclede County and in one or two in Crawford County are granite dikes or ridges which rise above the stratified rocks.

HARRISON,[56] in 1868, describes two localities in Washington County, where between the horizontal limestone and the solid porphyry are conglomerates consisting of water-worn pebbles and bowlders, all of porphyry, cemented together by a calcareous matrix. Interstratified with the limestone are also thin layers containing water-worn porphyry pebbles. It is therefore concluded that the porphyry hills existed as such before the Silurian hills were deposited.

PUMPELLY,[57] in 1873, states that the Archean (Azoic) rocks of southeastern Missouri form an archipelago of islands in the Lower Silurian strata, which surround them as a whole and separate them from one another. They appear as knobs 1,400 to 1,800 feet above the sea, and rising 300 to 700 feet or more above the valleys. The rocks consist chiefly of granites and felsitic porphyries. They reach their most extensive surface development in the region forming the northern part of Madison, Iron, and Reynolds and the southern part of St. Francis and Washington counties. This series is the near equivalent in point of age to the iron-bearing rocks of Lake Superior, New Jersey, and Sweden. The rocks overlying them belong to the oldest known members of the Silurian, but they may be the deep-seated equivalents of the Potsdam sandstone, or even older. Before the deposition of the Silurian the porphyries and granite had undergone an enormous amount of erosion, an amount at least several times as great as they have suffered since that remote time.

The surface of Iron Mountain has disintegrated and decomposed in mass, the entire porphyry hill being changed to a clay. Disintegration has often taken place to a depth of certainly more than 50 feet in the granites of Madison County. The iron ore of Iron Mountain is a residuary deposit, having its origin in the gradual removal of the existing crystalline rocks and leaving behind the iron ore.

Pilot Knob is composed of more or less massively bedded porphyries, porphyry conglomerates, and beds of hard specular ore. These strata strike N. 50° W. and dip on an average 13° southwest by south. The top of the knob consists of stratified porphyry conglomerate with a thickness of 140 feet. This rock is made up of small and large, more or less angular, pebbles of porphyry cemented together by iron ore and containing numerous layers and bodies of ore. At the base of this series is a great bed of ore divided into two parts by a thin slate seam. Immediately below the ore is porphyry, which continues to the base of the hill.

The rocks forming the southwestern flank of Cedar Hill are the extension of the conglomerates and ore beds of Pilot Knob. Manganese ores are found associated with the porphyritic rocks, and in sec. 16, T. 33 N., R. 2 E., in Reynolds County, the manganese ore is one of the members of a series of bedded porphyries. At this locality metamorphic limestone is one member of the porphyry series, but it is now, by physical and chemical agents, greatly changed from its original condition and is very manganiferous. Another member of this same succession is a porphyry conglomerate or breccia, consisting of pebbles of red and compact porphyry containing grains of quartz and crystals of feldspar and cemented by porphyry of a similar character. This rock resembles the Calumet-Hecla conglomerate of Lake Superior.

Schmidt,[58] in 1873, also describes the iron-ore deposits of Iron Mountain, Pilot Knob, Shepherd Mountain, Cedar Hill, Buford Hill, Big Bogg Mountain, Lewis Mountain, Cuthbertson Bank, and Hogan Mountain. The succession at Cedar Hill includes slates of red-banded porphyry, stratified quartz porphyry, slates of red porphyry, green porphyry, banded jasper, and jasper with specular ore.

Shumard,[59] in 1873, states that granite is found in Laclede, Crawford, and Ste. Genevieve counties.

Broadhead and Norwood,[60] in 1874, describe granite and porphyry at numerous points in Madison County. On the west side of St. Francis River, in the NW. ¼ NE. ¼ sec. 33, T. 34 N., R. 5 E., there is an exposure of sandstone and conglomerate resting directly on the granite.

Haworth,[61] in 1888, states that the Archean area of Missouri covers an irregularly outlined portion of no less than ten different counties and extends to the west as far as Texas County, to the north and northeast as far as Washington, St. Francois, and Ste. Genevieve counties; to the east it passes through Madison County, and to the south nearly through Wayne County; but only a small portion of this territory is covered by Archean rocks. The rocks are the different kinds of porphyry, which predominate, granite, and dikes of diabase and diabase porphyry. Numerous instances were observed where the stratified rocks overlie the massive ones and are nonconformable with them. Nowhere at the contact zone was metamorphosed limestone or sandstone observed. The granites, so far as observed, occur on low ground, while the hills are almost invariably composed of porphyry. At numerous places dikes of various sizes occur, sometimes in the granite and sometimes in the porphyry and, as stated by Broadhead, sometimes in the sandstone. Detailed descriptions are given of the granites, porphyries, and dike rocks.

Pumpelly and Van Hise,[62] in 1890, find that at Iron Mountain the ore (specular hematite), in its original position, occurs in the form of veins in the porphyry. These veins are sometimes of very considerable thickness, running as high as 30 feet. They vary from this size to those much smaller, ramifying through and cutting the porphyry in various directions. In some places on the mound between the stratified sandstone and the porphyry is a pre-Silurian mantle of detrital material, which is largely composed of fragments of the vein ore. The chief mining at the present time is from a mass of bowlders of the iron ore in a pre-Silurian ravine. In the process of disintegration the more resistant and heavier masses of iron ore have been concentrated in the upper slopes of the ravine, forming a deposit analogous to a placer. The vast amount of this iron ore in these ravines, as well as that which occurs as a residuary deposit upon the mound, indicates that in pre-Silurian time there was here an enormous erosion, otherwise this quantity could not have accumulated from the relatively sparse and small veins of iron ore in the mountain. The Pilot Knob iron-ore bed was found to grade upward into a conglomerate, the matrix of which is largely composed of ore and most of the pebbles of which are porphyry. The whole appearance of the deposit is that of a detrital one, and the question arises whether this bed has been produced from the erosion of earlier vein deposits in the porphyries, such as are found in Iron Mountain. Pilot Knob itself bears the same relations to the Silurian as does Iron Mountain, and if this suggestion as to the origin of the Pilot Knob ore is correct, it implies that the pre-Silurian history has been not only very long but complex.

HAWORTH,[63] in 1891, describes the crystalline rocks in the vicinity of Pilot Knob, Mo. These are chiefly porphyries, felsites, and breccias. These rocks are regarded as Archean in age, because there is no contact metamorphism between them and the surrounding Paleozoic rocks; and because in the Paleozoic sandstones and limestones are numerous fragments of the crystalline rocks. The crystalline rocks are regarded as of eruptive origin, as shown in the field by the absence of bedding, by flow structure, by banded structure, by lithophysæ, by breccia, by scoria, by amygdaloids, by tuffs, and by absence of gradations into noncrystalline rocks, and as shown by the microscope by the texture of the groundmass in the porphyries and breccias, by flow structure in them, by magmatic corrosion of porphyritic crystals and fragments of the breccias, and by other phenomena. The laminated ferruginous rocks of Pilot Knob and of other localities are regarded as volcanic breccias. As evidence of this it is said that this material passes into the porphyry, that the fragments are all of porphyry or felsite, and that the groundmasses of the breccias or conglomerates are always felsitic or porphyritic, the apparent detrital fragments being merely set in a lava of a similar character.

NASON,[64] in 1892, fully describes the iron ores of the porphyry region of Missouri, and incidentally treats of the associated rocks. The porphyries usually show evidence of bedding, but this may be that of igneous flows. The Cambrian limestones and sandstones flank and rest unconformably upon the granites and porphyries.

The iron ore of Iron Mountain and most of the other localities is in veins in the massive rock, probably of water-infiltrated origin; or in a residuary mantle; or as concentrated detritus along the slopes or ravines of the porphyries. In the two latter cases the ore is derived from the veins. In some cases this concentration occurred before or during the deposition of the Cambrian sandstones and limestones, but in other cases is subsequent to the deposition of these rocks. At Pilot Knob the succession from the base upward is: Porphyry; conglomerate; a slaty ripple-marked stratum in contact with the ore body; main ore body 19 to 29 feet thick; highly ferruginous slate, 1 to 3 feet thick; heavy beds of conglomerate with an average thickness of 100 feet. The pebbles of the conglomerate are mainly derived from the porphyries, but the regularly laminated slate and ore have a thin-bedded structure, which is such as to lead to the conclusion that they are undoubtedly of sedimentary origin.

Winslow,[65] in 1893, places in the Archean the granites, porphyries, and felsites of Missouri, and in the Algonkian the associated conglomerates, one of them bearing the Pilot Knob iron ore.

Keyes,[66] in 1895, in an account of the characteristics of the Ozark Mountains, briefly describes the Archean and Algonkian rocks of the region. Archean rocks occur at the east and west ends of the Ozark uplift. The best known of the areas is the eastern one, the Iron Mountain district of southeastern Missouri. Here the largest areas occur in the vicinity of the peak from which the district takes its name, and other smaller areas are scattered over a considerable range of adjacent territory. The Archean rocks in the Iron Mountain district are granites and porphyries, the latter predominating, both of which are broken through in numerous places by basic intrusives.

At the western end of the Ozark uplift, in Indian Territory, are Archean rocks, principally granites, of which there are many varieties, cut, as in southeastern Missouri, by dikes of basic material.[a]

Immediately overlying the Archean in a number of places are beds of conglomerates and slates provisionally referred to the Algonkian. These appear to best advantage on Pilot Knob.

Haworth,[67] in 1895, maps and fully describes many areas of pre-Cambrian crystalline rocks of Missouri. These occur in irregular areas and isolated hills extending over an area 70 miles square in the southeastern part of the State. The rocks consist of granites, granophyres, and porphyries, which are occasionally cut by diabase dikes. Some of the granophyres are located between the granite and the porphyry areas, and seem to be a connecting link between them. At other times they are in contact only with the granite or with the

[a] Pre-Cambrian rocks of Indian Territory occur only in the Arbuckle uplift. The Arbuckle uplift in southwestern Indian Territory trends west-northwest and east-southeast and is in no sense to be connected with the structure of the Ozark region.

porphyry, in which case the connections are traceable in one direction only. It is concluded that all are different facies of a magma belonging to a single period of igneous activity. Associated with the pre-Cambrian are clastic beds occupying small areas, as, for example, at the summit of Pilot Knob.

HAWORTH,[68] in 1896, describes and maps the pre-Cambrian geology of the area of the Iron Mountain sheet in southeastern Missouri, which covers portions of Iron, St. Francois, and Madison counties. The pre-Cambrian rocks are crystalline massive Archean rocks and crystalline stratified Algonkian rocks.

The Archean rocks in general form the uplands. They may be divided into two general classes, basic eruptives and acidic eruptives, including granites and porphyries.

The basic eruptives, of remarkably uniform character, occur principally in the southeastern part of the area, usually in dikes cutting through the granites and porphyries, but in a few cases in the form of bosses almost circular in outline. The general trend of the dikes is northeast-southwest.

The granites occur mainly in two large areas, though they are found occasionally in small patches within the porphyries. The two areas are the Graniteville and Stouts Creek or St. Francois areas. The porphyries occur in numerous large, uniformly distributed areas, making up nearly half the area of the entire sheet. They include what have been called by other writers quartz porphyry, feldspar porphyry, felsite, felsophyre, and orthophyre.

Numerous observations show gradations between the granites and the porphyries, and it is concluded that these rocks were formed from the same or similar magmas, and that their difference in texture is due to crystallization under different conditions.

Algonkian rocks are found near the center of the area, capping the Archean rocks of Pilot Knob. They comprise conglomerates and slates, chiefly the former, and include the iron-ore deposits of the locality. The pebbles of the conglomerate are mostly derived from the porphyry. The matrix is a fine felsitic mass mixed intimately with varying amounts of hematite. In places the ore forms almost the entire body of the rocks.

Paleozoic rocks unconformably overlie the crystallines, and dip away from the Archean hills.

KEYES and HAWORTH,[69] in 1896, describe and map the geology of the Mine la Motte area, which includes portions of Ste. Genevieve, Madison, and St. Francois counties, Mo. Archean rocks, described by Haworth, occupy about half of the area of the sheet, forming the nucleus about which later formations are exposed in concentric belts. They are granites and porphyries, cut by dikes of diabase. The acidic rocks greatly predominate, the granite making up fully nine-tenths of the eruptives of the area. The porphyry appears to be the surface facies of the granite, and seems to graduate downward into the latter. This is shown where erosion has been great and has left high granite hills, which are often capped by porphyry.

Cambrian rocks directly overlie the Archean rocks, with unconformable relations.

KEYES,[70] in 1896, considers the granites and porphyries in the eastern part of the Ozarks. Agreeing with Haworth, he finds the granites and porphyries to be different facies of the same magma. Further agreeing with Haworth, he finds that the granite occupies the lower ground, the porphyries the higher ground, and that, where there are gradations between the two, the granites are at the base of the hills while the porphyries are at the top, with transition zones between. The granites occupy a comparatively small area in the northeastern part of the district. This is an area of low elevation and near Mississippi River, and distribution is explained as due to differential erosion. The physiography of the district is discussed, and the conclusion is reached that the crystalline rocks have undergone very considerable erosion since Cambrian time. Agreeing with Van Hise, it is held as probable that the granites and porphyries are of Algonkian age. A deep boring near Kansas City at a depth of 2,500 feet penetrated black foliated mica schist, which has the characteristics of the Archean rocks.

KEYES,[71] in 1896, in connection with a description of the clay deposits of Missouri by Wheeler, briefly discusses their geological occurrence. Most of the ore-bearing conglomerates of Pilot Knob and vicinity, heretofore called Algonkian, are believed to be Cambrian. The granites and quartz porphyries of the region are not really of Archean age, as generally considered, but are probably Algonkian. In chemical, mineralogical, and structural characters, and in absence of dynamic effects, they differ from the gneissic and schistose rocks which have been reached in deep drill holes, and therefore they are believed to be younger than such gneissic and schistose rocks (which, it may be inferred, are believed to represent the Archean).

The geological conditions of the crystalline rocks are unfavorable to clay deposits.

BUCKLEY and BUEHLER,[72] in 1904, map and describe the pre-Cambrian granites of southeastern Missouri in connection with a report on the building stones of the State.

SUMMARY OF PRESENT KNOWLEDGE.

In southeastern Missouri and in Camden County of south-central Missouri are pre-Cambrian islands surrounded by Cambrian sediments. The pre-Cambrian consists mainly of granites, felsites, porphyries, and porphyritic breccias. Haworth describes gradations between the granite and the porphyritic rocks. At Pilot Knob and in the adjacent area are found water-deposited rocks which comprise porphyry conglomerates, fine-grained beds of the same character, and well-bedded iron ores and ferruginous slates. The porphyry sediments and the iron-bearing rocks are interbedded in such a way as to suggest a deposition under water of nonfragmental iron-formation material similar to that in the Lake Superior region, this deposition being interrupted by the accumulation of volcanic material which itself was to a considerable extent worked over by water. The iron ores and associated ferruginous slates have all the aspects of Lake Superior ores derived from the alteration of original bedded iron carbonate or ferrous silicate formations. Iron ores found at Iron Mountain occur largely as great irregular masses and veins in the porphyry and may be of different origin. The relations of the sedimentary rocks to the massive granites and porphyries are not known. The unaltered horizontal Paleozoic rocks rest on the deeply eroded crystalline rocks, the conglomerates adjacent to Pilot Knob and Iron Mountain containing numerous bowlders of iron ore.

There is, then, in southeastern Missouri a pre-Cambrian clastic series associated with igneous rocks which may be either older or younger. The rocks show resemblances to both Archean and Algonkian rocks of the Lake Superior country, and there is no way to separate them. They are accordingly mapped as pre-Cambrian.

SECTION 5. OKLAHOMA.

SUMMARY OF LITERATURE.

Hill,[73] in 1891, finds in Indian Territory, in the heart of the area occupied by the Chickasaw Nation, a granite called the Tishomingo granite, which appears to be of pre-Paleozoic age.

Bain,[74] in 1900, describes the geology of the Wichita Mountains of Oklahoma. Gabbros and porphyries of pre-Cambrian and probably of Archean age are present. The gabbro is more prominent in the western portion of the mountains, being especially well developed in the Raggedy Mountains, and the porphyry is more common in the eastern part of the mountains, being typically developed at Carrollton Mountain.

Taff,[75] in 1904, describes and maps the geology of the Arbuckle and Wichita mountains, in Indian Territory and Oklahoma. In the Arbuckle mountains, southwestern Indian Territory, unconformably below middle Cambrian sediments, are granite, granite porphyry, and aporhyolite containing basic dikes. The granite (Tishomingo) occurs in the eastern part of the mountains, in a rudely triangular area 20 miles in length and 10 miles wide in its widest part, near the western end. The porphyry and aporhyolite areas occur in the Arbuckle Mountains proper, in the western end of the uplift.

In the Wichita Mountains, southern Oklahoma, pre-Cambrian granite, granite porphyry, and gabbro cut by diabase form a considerable part of the mountains. Granite is the principal mountain-making rock in the Wichita region. Its area is greater than that of all the other igneous rocks combined, and is about equal to that of the others and the older Paleozoic sediments. It makes all of the high land of the Wichita, Quana, Devils Canyon, and Headquarters mountains, and a large part of the Raggedy group.

The gabbro is exposed for the most part in the valleys or on the plains which surround the mountains. The granite porphyry comprises practically all of the Carlton Mountains, the igneous mass lying between the Cambro-Ordovician limestone hills in the vicinity of Blue Canyon, north of Mount Scott, and some hills composed of the same class of rocks southwest of Fort Sill.

In the Wichita Mountains, as in the Arbuckle uplift, the middle Cambrian sediments lie on the eroded surface of the igneous rocks. The basal deposits are composed to a large extent of detrital material from the contact and adjacent igneous rocks.

SUMMARY OF PRESENT KNOWLEDGE.

Rocks of apparently pre-Paleozoic age appear at two localities: (1) In the Arbuckle Mountains of southern Oklahoma, where granite, granite porphyry, and aporhyolite occur, supposedly of pre-Cambrian age. The granite, called the Tishomingo granite, is in the eastern part of the uplift, while the granite porphyry is in the western part. Both are cut by basic dikes. (2) In the Wichita Mountains, southern Oklahoma, are granite, granite porphyry, and gabbro, cut by diabase dikes. The closest correlation yet possible is a tentative one with the pre-Cambrian.

SECTION 6. TEXAS.

SUMMARY OF LITERATURE.

Roemer,[76] in 1848, mentions granitic rocks at several points—15 miles north of Fredericksburg, on the banks of the Llano, in the country between the Llano and San Saba, and between Pedernales and San Saba rivers. These granitic rocks are surrounded by Paleozoic strata.

Shumard,[77] in 1860, describes rocks in Burnet County upon which rest directly the fossiliferous Potsdam.

Shumard,[78] in 1861, describes the Primordial rocks of Texas as resting upon reddish feldspathic granite very similar in character and composition to the granites of Iron Mountain, Missouri.

Buckley,[79] in 1866, states that the known Azoic rocks of Texas are mostly in Llano and adjoining counties. There are here granites with steatite or soapstone, immense beds of iron ore, and metamorphic rocks, consisting chiefly of slates, mica schist, and gneiss with quartz veins. The granites of Burnet County probably belong to a later period of elevation than the Azoic. Here the metamorphic rocks are on the outskirts of the granite, in nearly vertical, more or less broken or contorted strata. In Mason County are highly inclined micaceous shales. At Packsaddle Mountain are dark shales which, near Honey Creek, extend unconformably beneath the nearly horizontal layers of Potsdam sandstones and limestones. In Mason County is a very large deposit of iron ore, which is believed to be a true vein. Another bed of iron ore lies between two granite ridges and is traversed by veins of quartz. House Mountain, consisting of granite, is capped by massive beds of nearly horizontal sandstone. The Azoic rocks trend in a northeast-southwest direction, being on the same line of upheaval as the Ozark Mountains of Arkansas and the Iron Mountains of Missouri.

Buckley,[80] in 1874, describes as resting unconformably beneath the Potsdam, in Llano County, shales and argillites which lithologically resemble the old slates of Vermont and New Hampshire. They are barren of fossils. Locally a slaty cleavage is developed. Sometimes the slate is changed into a gneissoid rock, all gradations of the change being seen. Friable mica slates containing garnet sometimes underlie the granite. These rocks are referred to the Laurentian. Most, and probably all, of the granites of this region are of a later period than the metamorphic rocks associated with them. Associated with the granite in Burnet and Llano counties are immense beds of magnetic iron ore.

Buckley,[81] in 1876, describes Azoic granitic rocks in many of the mountain ranges west of Pecos River. At a number of places basaltic rocks occur. All the igneous rocks north of the Pecos are either of upper Cretaceous or Tertiary age, as is shown by the uptilted strata of these rocks.

Walcott,[82] in 1884, finds that the Potsdam sandstone rests unconformably on a great formation to which the term Llano group is applied. These rocks are alternating beds of sandy shales, sandstones, limestones, and schists, that have a dip of 15° to 40°. They are little metamorphosed. The overlying sandstone in its fossils is like the Tonto group of the Grand Canyon, and the Llano group is correlated with the Grand Canyon and Chuar series of the Grand Canyon on the basis of position and lithological character. The best exposures are at Packsaddle Mountain, in Llano County, where the horizontal Potsdam rests on the uptilted and eroded Llano beds. Across the valley of Honey Creek, 4 miles west of Packsaddle Mountain, the strata of the Llano group have been more metamorphosed, plicated, and broken by intrusive dikes of granite. The intrusive rocks are of pre-Potsdam age, but largely the result of extrusion of granite at or near the close of the erosion of the Llano. They are the chief cause of the metamorphism of the Llano rocks. No rocks of undoubted Archean age were observed.

Shumard,[83] in 1886, describes as eruptive rocks the granites, porphyries, and basic rocks which compose the whole of Wichita, Limpea, Hueco, and Mimbres mountains. In the Organ Mountains are partly sedimentary and partly eruptive rocks; while the Guadalupe, Sacramento, and Horse mountains are wholly sedimentary. None of these crystalline rocks are regarded as pre-Cambrian.

Glenn,[84] in 1890, describes the Azoic rocks as consisting principally of red granite, occasionally gneissoid, intersected by numerous nearly vertical dikes of quartz rock. West of the granite in Llano County is an extensive field of schist, sandstone, and limestone of uncertain age. At Spring Creek, in Burnet County, is also a small schist formation succeeding the granite. Were it not for the interposition of sandstone between the granite and the schists they would be assigned to the Azoic.

Comstock,[85] in 1890, divides the Archean rocks of central Texas into a Burnetan (Laurentian?) system and a Fernandan (Ontarian?) system.

The fundamental gneisses of the Burnetan occupy a lens-shaped area striking N. 75° W., and they are well exposed in Burnet County. Within the group there are no unconformities. The rocks of the system are largely gneisses, but they grade on the one hand into quartzose mica schists and on the other into friable sandy gneisses and fine-grained binary granites and graphic granite. Stratigraphically the group is divided into three series; these are, from above downward: (1) Bodeville, consisting of mica schist and chlorite schists (chiefly acidic); (2) Long Mountain, consisting of hornblendic and pyroxenic rocks (basic); (3) Lone Grove, consisting of gneiss, granite, etc. These rocks are compared with Lawson's Lake of the Woods Archean. The igneous eruptions of the Burnetan are of different ages, some of them earlier and some later than the Potsdam.

The Fernandan or Ontarian system is well exposed along the valley of San Fernando Creek. Its exposures are more extensive than those of any other pre-Cambrian system. While in the main there is little difficulty in distinguishing between Fernandan and Burnetan strata, metamorphism has caused a close resemblance in many exposures. The general succession is, from above downward: Calcareous rock, chloritic slates and shales, carbonaceous schists, ferruginous rocks, quartzites, acidic schists, and basic schists. In this system are various eruptives, including granites, quartz dikes, and basic rocks. Whenever the Fernandan beds are visible in connection with the Burnetan strata, through their own excessive erosion or by reason of the persistence of prior elevations of the earlier system, there is always abundant evidence of unconformity; and if any fractures occur, the joints of the northwest (Fernandan) trend invariably cross and cut the strike of the Burnetan rocks. Additional support for the unconformity of the two systems is gained from the fact that contortions occur in the lower system only where this or later trends affect its continuity. Moreover, the composition and texture of the Fernandan beds are to a large extent that of derivatives of the Burnetan lithological series.

Above the Fernandan system is an Eparchean group of rocks, the stratigraphic affinities of which are nearer the Archean than the Cambrian. There is no doubt that they rest unconformably below the Paleozoic. To this group, including Walcott's Llano group, is given the term Texan (Algonkian?) system. The rocks of the Texan system are chiefly siliceous, but shales and limestones are not wanting. The succession includes, from the base upward: A set of micaceous sandstones, with thinly laminated shales and chloritic detrital material; hard, white, laminated quartz rock or quartzite, associated with ferruginous and schist layers; ferruginous shale beds, in part somewhat graphitic, and limestones or marbles. It is often difficult in the field to distinguish the graphitic shale and marble, as a belt, from the similar lithological set of the earlier Fernandan system. In hand specimens, however, the distinction is obvious. The Texan beds are much less altered, as a rule. The graphitic strata are plainly derivatives of the preexisting graphite schists, and the marbles are white or brown, instead of blue. The Packsaddle marbles and shaly beds are compared with the Chuar; the Llano quartzites and sandstones, with eruptives, with the Grand Canyon; and the Mason sandy shales and schists with the Vishnu series.

There must have been a vast amount of erosion after the folding of the Texan strata and prior to the deposition of the Cambrian sediments upon the upturned edges. The outcrops of the Texan strata are almost invariably accompanied by some of the Fernandan beds, or by members very closely resembling these, often in such relations as to make it difficult to determine the boundary between the two groups upon structural grounds alone; but the rocks here included as of the Texan system are never involved in an earlier uplift than the north-south trend.

Comstock,[86] in 1891, further describes the relations of the pre-Cambrian rock series of central Texas. The Fernandian system is held to rest unconformably upon the Burnetian, because no other terrane within the Burnetian has structural planes or breaks following a course N. 75° W., while every other axis of uplift is traceable through the rocks of the Burnetian system, and because the basal members of the Fernandian system are made up in part of material apparently derived from the Burnetian rocks. That the Texian (Algonkian?) system rests unconformably upon the Fernandian is concluded from facts of the same character as those which show the discordance between the Burnetian and the Fernandian. The nearly due north-south strikes of these rocks are commonly peculiar to them, the earlier fractures and lines of uplift being invariably absent, but the later ones can be more or less distinctly traced through the members of this system. There are localities exhibiting the juxtaposition of the Texian with the underlying Fernandian, in which the nonconformity between the two is seen. These relations are seen south and southeast of Packsaddle Mountain, southwest of Sharp Mountain, in portions of the country north of Lockhart Mountain, north and northeast of Mason, in the Beaver Creek valley, and elsewhere in Mason County. Further, the derivative character of the Texian beds is a marked feature. In the Fernandian is a great development of magnetites. While these deposits appear to be in discontinuous lenses or bosses across the region, there is almost always an indication of continuity in the shape of a line of ferruginous soil or other landmark. The iron deposits have above them carbonaceous and calcareous beds and below them quartzose beds.

Osann,[87] in 1896, gives the geology and petrography of the Apache (Davis) Mountains of western Texas. The oldest rocks found therein are the crystalline schists, which compose the greater part of the Carrizo and Van Horn mountains. Here is found a great set of coarsely crystalline gneiss, mica schist, and associated schistose rocks. These have in general a parallel northwest-southeast strike, which agrees with the axis of the range. Following Professor von Streeruwitz, Osann places these with the fundamental rocks.

Walcott,[88] in 1899, states that the Llano series of Texas is a series of alternating sandy shales, sandstone, and limestone, very similar to those of the Grand Canyon pre-Cambrian series and overlain by a middle Cambrian sandstone similar to the Tonto sandstone of the Grand Canyon district. No fossils have been found in these rocks, but no systematic search has been made.

Richardson,[89] in 1904, describes the pre-Cambrian (?) rocks in El Paso County, Tex., and he has prepared the following summary for this bulletin:

There are two areas in which rocks of probable pre-Cambrian age are exposed, one in the Franklin Mountains and the other south of the Sierra Diablo. The Franklin Mountains are a narrow range which extends northward from El Paso, and is composed chiefly of westward-dipping Paleozoic strata. These consist of 300 feet of Cambrian sandstone and about 5,000 feet of limestone containing lower and upper Ordovician, Silurian, and upper Carboniferous fossils. The Devonian and lower Carboniferous are unrepresented by sediments. Coarse red granite, of probable post-Paleozoic age, extends along the eastern base of the mountains, and crosses the range in one locality. The pre-Cambrian (?) rocks occur along the central eastern slope and also constitute the culminating point of the range. They consist of quartzite and rhyolite porphyry, which outcrop in several disconnected areas, the most complete section occurring in the central part of the mountains 10 miles north of El Paso. The lower portion is composed of about 1,800 feet of fine-textured, thoroughly indurated quartzite, which has been intruded by a few dikes and sills of diabase. The quartzite is succeeded by rhyolitic conglomerate, ranging from 0 to 400 feet in thickness, which contains pebbles of the underlying quartzite. Thin sheets of rhyolite porphyry locally occur, intercalated in the conglomerate, which is overlain by a mass of rhyolite porphyry about 1,500 feet thick. The porphyry is a massive red rock consisting of phenocrysts of quartz and feldspar in a dense groundmass, and apparently lies parallel to the underlying strata. The entire series dips westward at an angle of about 20°, conforming with the general structure of the Franklin Mountains. At the top of the section the basal bed of Paleozoic sandstone contains pebbles of the underlying rhyolite porphyry and rests unconformably upon it. The sandstone contains brachiopod shells, determined by Walcott as either upper or middle Cambrian. The underlying rocks, therefore, are probably pre-Cambrian.

South of the Sierra Diablo, between Eagle Flat and Van Horn stations on the Texas and Pacific Railway, about 100 miles southeast of the Franklin Mountains, there is a more or less metamorphosed complex, consisting of red sandstones, cherty limestone, breccia, and a few igneous intrusions; and an area of schistose rocks is exposed south of the railroad adjacent to Allamoore. The less metamorphosed rocks which are exposed north of the railroad have been tilted, folded, and faulted, the main structural trend being east and west. The outcrops for the most part are low lying, and are separated by flat, wash-filled areas, so that a complete section can not be measured. Apparently the oldest rock in the area north of the railroad is a homogeneous, fine-textured, bright red sandstone, which is at least 500 feet thick. Associated with the sandstone are several hundred feet of massive magnesian limestone seamed with crumpled bands of chert, and an indurated, coarse breccia-conglomerate composed of fragments of fine red sandstone and cherty limestone. In places these rocks have been cut by both acidic and basic dikes.

The schistose area south of the Texas and Pacific Railway is composed of altered siliceous strata consisting of quartz schists, quartzites, and clay slates, together with subordinate basic igneous rocks which have been altered to chlorite schists. These rocks outcrop in an area of dissected ridges and intervening valleys which trend northeast-southwest. The ridges are underlain by hard rocks and the valleys by softer ones, the topographic trend corresponding with the strike of the rocks. The dip is steep southeastward, varying between 25° and 85°.

The relations of the rocks in the two areas north and south of the railroad are concealed by Quaternary wash deposits. In both areas the tilted ancient rocks are overlain by almost flat-lying Paleozoic strata which contain a basal conglomerate composed of pebbles of the underlying rocks. The lowest of these is a coarse red sandstone averaging about 400 feet in thickness, of probable Cambrian age, but in which no fossils other than annelid borings have been found. This sandstone is overlain by a thick mass of limestone that contains abundant fossils, determined by Ulrich to be of lower Ordovician (Beekmantown) age.

In both the Franklin Mountains and Sierra Diablo areas the pre-Cambrian (?) rocks are in large part of sedimentary origin, although, besides the fact that quartzites are present in both areas, there is little lithologic similarity in the deposits. The origin and stratigraphic relations of these trans-Pecos rocks suggest that they are probably equivalent to the Llano series of central Texas.

SUMMARY OF PRESENT KNOWLEDGE.

In central Texas is a series of sedimentary rocks, named Llano by Walcott, which consists of alternating beds of shales, slates, sandstones, quartzites, limestones, ferruginous rocks, carbonaceous or graphitic schists, mica schists, and chlorite schists. Comstock divides the sedimentary rocks into two "systems," between which he believes there is an unconformity. There also occur in this area granites and gneisses, a part of which are placed as a separate "system" by Comstock, but which are regarded by Walcott as intrusive in the sedimentary rocks. Whether all of the granites or gneisses are intrusive or not, it is agreed by both that the clastic series are cut by numerous eruptives, both basic and acidic, of which granite is the most prominent. Resting unconformably upon the deeply eroded pre-Cambrian are the Cambrian ("Potsdam") rocks. It is clear that in central Texas there is one, and possibly two, series of Algonkian rocks, but whether the Archean is also represented is as yet undetermined. The sedimentary rocks of the Texas area have been correlated by Walcott and Comstock with the Algonkian of the Grand Canyon region.

J. A. Taff and E. O. Ulrich, by studies made in 1902 in Llano and San Saba counties, Tex. (results unpublished), found that the Cambro-Ordovician section of grits, sandstone, limestone, and dolomite is identical with the Cambro-Ordovician section in the Arbuckle and Wichita mountains of Indian Territory and Oklahoma, and that the Cambrian, probably "Potsdam" of Walcott, rests on the eroded surface of granite cut by basic dikes. These granites probably belong to the intrusives in Walcott's Llano series.

Rocks of ancient age also appear in western Texas. According to G. B. Richardson (see summary, pp. 746–748), in El Paso County there are two areas of probable pre-Cambrian rocks. One is in the Franklin Mountains and the other is south of the Sierra Diablo adjacent to the Texas and Pacific Railway. In the Franklin Mountains the pre-Cambrian rocks consist of a monoclinal succession of quartzite overlain by rhyolite, intruded by diabase and granite, and overlain unconformably by Cambrian. South of the Sierra Diablo is a complex of red sandstone, cherty limestone, breccia, igneous intrusions, and schistose rocks, all overlain unconformably by Paleozoic strata.

The rocks of these two areas are tentatively considered to be equivalent to the Llano series of central Texas.

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[71] Clay deposits, by H. A. Wheeler—The geological occurrence of clays, by C. R. Keyes. Rept. Missouri Geol. Survey, vol. 9, 1896, pp. 36–37.

[72] Quarrying industry of Missouri, by E. R. Buckley and H. A. Buehler. Missouri Bur. Geology and Mines, 2d ser., vol. 2, 1904, with geological map.

[73] Notes on a reconnaissance of the Ouachita Mountain system in Indian Territory, by R. T. Hill. Am. Jour. Sci., 3d ser., vol. 42, 1891, pp. 11–124, with sketch map.

[74] Geology of Wichita Mountains, by H. Foster Bain. Bull. Geol. Soc. America, vol. 11, 1900, pp. 127–144, pls. 15–17, with sketch map.

[75] Preliminary report on the geology of the Arbuckle and Wichita mountains in Indian Territory and Oklahoma, by Joseph A. Taff. Prof. Paper U. S.

Geol. Survey No. 31, 1904, with geological map. See also Geologic Atlas U. S., folio 98, U. S. Geol. Survey, 1903.

[76] Contributions to the geology of Texas, by Dr. Ferdinand Roemer. Am. Jour. Sci., 2d ser., vol. 6, 1848, pp. 21–29. See also Texas, etc., 1849, pp. 464, with a map.

[77] Letter from B. F. Shumard. Trans. Acad. Sci. St. Louis, vol. 1, 1860, pp. 672–673.

[78] The Primordial zone of Texas, with descriptions of new fossils, by B. F. Shumard. Am. Jour. Sci., 2d ser., vol 32, 1861, pp. 213–221.

[79] Prelim. Rept. Geol. and Agr. Survey Texas, by S. B. Buckley. Austin, 1866, pp. 81, 4.

[80] First Ann. Rept. Geol. and Agr. Survey Texas, by S. B. Buckley. Houston, 1874, pp. 142.

[81] Second Ann. Rept. Geol. and Agr. Survey Texas, by S. B. Buckley. Houston, 1876, pp. 96.

[82] Note on the Paleozoic rocks of central Texas, by Charles D. Walcott. Am. Jour. Sci., 3d ser., vol. 28, pp. 431–433.

[83] A partial report on the geology of western Texas, by Prof. Geo. G. Shumard. Austin, 1886, pp. 145.

[84] A preliminary report on the geology of the State of Texas, by John W. Glenn. First Ann. Rept. Geol. Survey Texas, 1889, E. T. Dumble, State geologist, pp. 245–246.

[85] Preliminary report on the geology of the central mineral region of Texas, by Theo. B. Comstock. Idem, pp. 239–391.

[86] Report on the geology and mineral resources of the central mineral region of Texas, by Theo. B. Comstock. Second Ann. Rept. Geol. Survey Texas, 1890, E. T. Dumble, State geologist, pp. 553–664, 2 maps.

[87] Beiträge zur Geologie und Petrographie der Apache (Davis) Mountains, West-Texas, by A. Osann. Min. pet. Mitt., vol. 15, pts. 5, 6, 1896, pp. 394–456, pls. XI–XII.

[88] Pre-Cambrian fossiliferous formations, by Charles D. Walcott. Bull. Geol. Soc. America, vol. 10, 1899, pp. 199–244.

[89] Report of a reconnaissance in trans-Pecos Texas, north of the Texas and Pacific Railway. Bull. Univ. Texas Min. Survey No. 9, 1904.

CHAPTER XIII.

THE CORDILLERAS.

SECTION 1. MEXICO AND CENTRAL AMERICA.

SUMMARY OF LITERATURE.

SAPPER,[1] in 1894, describes and maps considerable areas of Azoic formations in Guatemala. The lowest formations are gneiss and the higher formations are mica schists and phyllites, associated with which are crystalline limestones, actinolite schist, and quartzites. Closely associated with these schistose rocks are ancient eruptive rocks, including granite, diabase, etc. Whether these Azoic formations are pre-Paleozoic or not can not as yet be asserted.

SAPPER,[2] in 1896, describes the geology of Chiapas, Tabasco, and the Peninsula of Yucatan, and mentions the occurrence of Azoic rocks in the Sierra Madre. These rocks include gneiss, mica slates, and phyllites. A band in the first northern range of the sierra, near the plantations of Piedad and San Vicente, trends N. 70° W. and dips 5° NE. Among the bowlders washed down by Aguacate River may be seen gneiss, mica slates, and phyllites, which indicate the presence of the crystalline formations also in the interior of the Sierra Madre.

AGUILERA,[3] in 1897, gives a synopsis of the geology of Mexico. The most ancient, or Azoic, rocks are granites, gneisses, and schists, presenting many variations. They extend lengthwise along the Pacific coast, forming a narrow band, interrupted in places, and sending ramifications toward the central part of the country, in some places almost to the eastern coast. They occupy the southern part of the State of Puebla, a part of the Sierra Madre in Chiapas, and extensive portions of Oaxaca and Guerrero; they are found also in Zacatecas, around Fresnillo; in Guanajuato, in the vicinity of the capital; in Sinaloa, around the crests of the Sierra Madre; in Sonora, in its northwestern and western parts; in Lower California, where they constitute the central Cordilleran axis of the peninsula, and in Veracruz, in its western region, limited by Puebla, in the canton of Zongolica.

In the southern part of Puebla and in Guerrero and Oaxaca, where the greater part of the exposures occur, the sequence is as follows, from the base up: (1) Porphyritic gneiss, similar to augen gneiss, at the base losing its lamination and passing into a kind of granite. (2) Phyllite gneiss, resting upon and grading below into preceding beds. (3) Very abundant mica schist, in some places garnetiferous, and in perfect conformity with the phyllite gneisses. (4) Phyllites, very argillaceous in the upper part, and toward the base showing gradual diminution in the proportion of clay. In accordance with this change of composition, the structure varies from perfectly schistose to laminated and finally to stratiform.

After the deposition of the argillaceous phyllites, and before the termination of the Paleozoic, there have occurred numerous eruptions, in order of age as follows: Granite gneiss, granite, granulite, hornblende granite, pegmatite, greisen, and diorite.

See the following summary by Ordoñez for references to other articles on the pre-Cambrian of Mexico.

SUMMARY OF PRESENT KNOWLEDGE OF MEXICO.

The following summary has been prepared by Señor Ezequiel Ordoñez, formerly of the Mexican Geological Survey:

LOCATION, IMPORTANCE, AND CHARACTER OF PRE-CAMBRIAN AREAS.

The areas which the pre-Cambrian rocks occupy in Mexico are very small compared with the very large and uniform areas of Mesozoic, Tertiary, and post-Pleistocene formations which cover Mexico and define in a general way the different geographic zones, of which the principal are the eastern, the western, and the central.

The pre-Cambrian rocks are found chiefly in the Pacific coast region of Mexico. They occur sometimes in belts, more or less narrow, and again in small, irregular areas, the outlines of which have not been determined with exactness.

The most noticeable feature of these primitive formations is that at present in many parts they do not in any direct manner affect the physical relief of the country; that is to say, they appear entirely subordinate to the bolder relief shown by the more recent Mesozoic and the eruptive Tertiary rocks, both of which cover more than half of the country in its most mountainous regions.

Throughout the Pacific coast zone, not considering Lower California, the pre-Cambrian rocks are found in small areas irregularly scattered in the northwestern States of Mexico, such as Sonora and Sinaloa, occupying the lower part of the western flanks of the Sierra Madre Occidental, or they rise as low, isolated knobs or hills in the coastal plains without any well-marked connection with the component orographic elements of the Sierra Madre.

In the central part of this Pacific coast region, between the parallels of latitude 19° and 24° north, there is a very marked interruption in the occurrence of these pre-Cambrian rocks, which here almost disappear, or are found in very limited areas. Instead there is in this wide zone an abundance of volcanic rocks, principally of a recent epoch, the flows of which at many points have covered the area to the shores of the ocean.

In the southern part of Mexico, approximately in the isthmian region, the pre-Cambrian rocks acquire greater relative importance. Beginning as a narrow belt in the vicinity of Zihuatanejo, the formation broadens gradually toward the southeast of Acapulco, and continues yet broader into the southern districts of the State of Puebla and the coastal region of Oaxaca. Narrowing again, the formation trends toward the isthmus of Tehuantepec, and continues very narrow in the State of Chiapas, whence a narrow belt curving toward the Atlantic crosses the territory of Guatemala, as has been demonstrated by the studies of Sapper.[a]

APPARENT DISCONTINUITY OF AN ARCHEAN BELT.

Even in the central part of southern Mexico and in the isthmian region these rocks are by no means continuous, since belts or zones of rocks probably Mesozoic, and also more recent coastal and marine formations, cover them in many places. Geologically, we can assume that the Archean formations are continuous there and form a general basement in the larger part of the coast districts of the States of Guerrero, Oaxaca, and Chiapas.

MEXICAN PRE-CAMBRIAN ROCKS MUST BE ARCHEAN.

We shall not again use the term pre-Cambrian, because it has not yet been possible to distinguish the different divisions of the Archean in these Mexican formations, or even to decide what part should correspond to the Algonkian, or to recognize a lapse of time between the Archean and the Paleozoic. As will be seen from the map, we have not definitely marked the outlines of the areas, and have left out of consideration the patches of more recent rocks which are to be found throughout the said areas.

TECTONIC IMPORTANCE OF THE ARCHEAN BELT.

Some foreign geologists have been surprised at the limited area of the Archean rocks in Mexico and have given to the known occurrences of this formation in Mexico an areal importance greater than they possess.

Felix and Lenk[b] have without reason designated the southern belt of the Archean rocks as the "Pacific Archean Cordillera;" they have

[a] Sapper, Carl, Grundzüge d. physikalischen Geographie von Guatemala, Gotha, 1894.

[b] Felix, J., and Lenk, H., Ueber die tektonischen Verhältnisse der Republik Mexiko: Zeitschr. Deutsch. geol. Gesell., vol. 13, 1892.

not taken into account the little part, if any, which these rocks have in the structure of the mountain range that we call the "Sierra Madre del Sur," which extends between the river Balsas and the table-lands of Puebla and Oaxaca on the one side and the low, slightly undulating lands of the coasts of Guerrero and Oaxaca on the other. With much less reason could we speak of an Archean Sierra or Cordillera in the west of Mexico in view of the position and restriction of the crystalline areas. Aguilera[a] has made a complete refutation of the idea of this so-called Archean Cordillera, which, even if it has existed in epochs very remote, there is no occasion to consider now as such, since there is so slight a relief to these crystalline schists.

Whatever may have been the origin assumed for these masses of crystalline rocks, and whether or not they form a basement upon which rest the newer sediments and the volcanic rock, an important question confronts us, namely, whether these crystalline rocks really form a continuous belt, elevated above the sea level and only hidden by the later sediments and the volcanic eruptives, or whether, as they appear to-day, they form islands, more or less separated, projecting through the other formations. We are naturally inclined to believe (as far as it is possible to arrive at such facts) that the crystalline rocks constituted primarily a continuous belt, which has been subjected in all its parts to innumerable changes—foldings, elevations, depressions, intrusions of foreign rocks, etc.—and that little by little, through the effect of the same forces which have modified them, the crystalline belt has been broken and the separate blocks have been moved independently. The numerous prominences thus caused in the belt have had the effect of giving the exposed parts of the formation the character of an archipelago, or a long cordon of islands, formerly much more numerous and extensive than those which we now discover, because considerable portions of the formation have been hidden by the later rocks of varying depths.

In the ocean depths an actual continuity probably exists. This is probable, not on the a priori assumption that these Archean rocks are the foundation upon which rest the later formations (they must have some support), but because these younger formations rise enormously, building the Sierras, supported by the Archean, thus justifying the assumption that beyond the narrow littoral platform, which extends some tens of kilometers, these rocks are submerged to the bottom of the steep-shored depression of more than a thousand fathoms which extends along the Mexican-Pacific coast regions.

The determination of the early extension of the belt of crystalline rocks is very important, for it is the basis of the general tectonic study

[a] Aguilera, J. G., Sobre las condiciones tectónicas de la República mexicana, Tip. Sec. Fomento, 1901, pp. 20–21.

of the whole country, since the absence of Archean rocks in the heart of the Sierra Madre Occidental, in the Mesa Central,[a] and in the Sierra Madre Oriental argues much in favor of the theory recently advanced by Aguilera and expressed very clearly in his work on the tectonic conditions of Mexico[b]—that in the formation of the geotectonic lineaments of Mexico it is possible that the crystalline belt has acted as a zone of resistance, the general orientation of all the mountain systems of the country defining the aforesaid belt and causing along the well-marked curvature of the crystalline belt a region perpetually afflicted by active volcanoes. It is necessary to add that the Archean massif has acted as a resisting zone, not because it may have remained completely rigid, since we shall see that it has been exposed to numerous movements, but because it has not been moved harmoniously with the mass of the newer materials, which by their abundance and characteristic distribution are those which give to Mexico its true physiographic characteristics.

This independence of movement gives sufficient reason in itself for assuming the continuity of a single extended Archean mass lying under the waters of the sea and partly emerged, subject to forces which have an origin comparatively deeper.

We can not, unfortunately, enter upon a fuller consideration of this subject, but we can point out some conclusions which appear to follow from the influence which the Archean rocks have exercised or the obstacles which they have imposed to the movements of the extensive sedimentary formations. For example, if there existed a continuous crystalline belt, more or less broken, or it is better to say dislocated, along the Pacific coast line, which served as a resistant zone to the other rocks, especially the Mesozoic, or if there was a certain independence of movements between the one and the other, it appears probable, considering the actual position of the Sierra Madre Occidental with relation to these rocks and the essential volcanic nature of the said Sierra, that this Sierra has been created exactly on the contact of the crystalline rocks with the sedimentary Mesozoic rocks, and that this contact is consequently a kind of scar with Tertiary volcanic rocks intervening between the Archean and Mesozoic formations. To be sure, we do not everywhere see the Mesozoic rocks in immediate proximity with eruptive rocks of the Sierra on the side toward the Mesa Central, but this is due to the great elevation of the modern lacustrine sediments taking the greater part of the material of which these were formed away from the volcanic masses and refill-

[a] It has been assumed by geologists like Humboldt, Burkart, and others, recently among them Aguilera (Bosquejo geológico de México), that the slates which are much altered and of an ancient aspect, as those at Guanajuato, Zacatecas, Fresnillo, Catorce, etc., are Archean, but this remains to be proved. If the existence of Archean rocks in the region of the Mesa Central is some day proved, that would affirm even more strongly the importance of these rocks in the tectonic history of Mexico.

[b] Op. cit., pp. 29–31.

ing the great depressions which tectonic accidents left in the Mesozoic rocks, so that the modern sediments hide these rocks in the Mesa Central and only the most elevated parts surmount them.

To us it appears possible also, as we have said, that in the place where the crystalline belt has by its curvature resisted the continuation of certain movements of a continental character it has developed a region of maximum fracture, where there have arisen numerous volcanoes and where enormous masses of volcanic lava have flowed out.

A proof that the crystalline belt is not entirely rigid can be deduced from the persistence of certain vibratory movements which take place in the Archean region of the south of Mexico and which are transmitted to the central volcanic portion of the country. On the coasts of Guerrero and of Oaxaca, on the Isthmus of Tehuantepec, and in the submarine regions adjacent are developed numerous earthquakes. It is a proved fact that the Pacific coasts of Mexico have undergone in recent epochs sensible relative movement, and a submersion, real or apparent, can be verified now not only in the portions of the coast covered by the modern rocks but also in the Archean regions which touch the Pacific coast.

The Archean rocks are too remote from the densely populated centers of the country to have been studied and delimited with any precision. Without doubt it can be said that the series of crystalline schists and of granitic rocks which are found in each section are generally so diversified that it is not possible to correlate them to the extent that the Mexican Archean areas can be represented in the same way as those of other parts of America have been correlated by Van Hise.[a]

This inequality in the character and succession of the rocks of the different Archean exposures can not be taken always as a proof of their independence, because they have been deformed in a very different manner and have been subjected to a long-continued denudation; for during a long period of the Paleozoic era this Archean belt, parts of which we now see exposed, has been exposed to erosion, as can be judged from the absence of sediments belonging to this era, which would have rested upon them if they had been submerged in the water. So it can be understood that the Archean rocks have suffered enormous erosion, which is also indicated by the high intrusive knobs that jut out above the area of low relief of the crystalline schists.

PETROGRAPHIC CHARACTER OF ARCHEAN AREAS.

Generally in the Archean areas of Mexico only schists appear, and these are very crystalline; but in small areas there are found argil-

[a] Van Hise, C. R., Correlation papers, Archean and Algonkian: Bull. U. S. Geol. Survey No. 86, 1892.

laceous slates, phyllites, and phyllitic gneisses, to which Aguilera has referred.[a] These slates pass to gneiss and mica slates by insensible transitions, as was indicated by the author cited. We personally have not seen these gneissic phyllites in the Archean areas with which we are acquainted, but it is probable that they are present, particularly in the Archean areas farther in the interior—that is, in the upper part of all the groups—since it is a curious thing that in many places toward the interior of the country the crystalline strata of the later periods are found. At any rate, in the most extensive Archean regions, as near Acapulco, to the southwest of Oaxaca, and in Tehuantepec, are seen the crystalline schists, with very limited quantities of phyllites, not always observed in conformable stratification.

If we should try to establish a correlation with the large areas of the American continent our Archean in its larger extension would correspond with the Laurentian period of North America, because it shows chiefly slaty crystalline rocks which grade into the granite, as in general is set forth in the work of Van Hise. However, in order not to introduce error, we do not yet make any exact division of the Archean areas of Mexico. This problem remains for a later date, when our crystalline series and the few indisputable sediments, although metamorphosed, which rest upon them may have been further studied.

Of the intrusive granite rocks which appear through the crystalline schists, some traversed these rocks right after the deposition or the consolidation of the primitive schists, judging from the evidences found in them of their having followed the changes in the slate, as is the case in regard to certain granites which pass insensibly to gneiss. This gneissic granite is almost always perthitic and poor in colored minerals, and is much like some gneissic granites of the United States.

In order to give an idea of what classes of rocks enter into the constitution of our Archean areas we pass in review in a few words some of the more important of them. We are far from thinking that these few lines give an adequate idea of the crystalline rocks of each region, since our sources of information are very limited and incomplete.

INSIGNIFICANCE OF WELL-KNOWN PALEOZOIC SEDIMENTS IN MEXICO AT PRESENT.

In the first place let us say that it may seem somewhat exaggerated to assume that the Archean rocks, as ancient as they are, have anything to do with the movements of the rocks more recent, as the Mesozoic, or even with the eruptive Tertiary rocks, in view of the fact that there has intervened the enormous lapse of Paleozoic time, unless these Archean rocks serve as an obstacle. It seems more prudent to leave these questions until more is known of the Paleozoic

[a] Aguilera, J. G., Bosquejo geológico de México: Bol. Inst. geol. México, Nos. 4, 5, 6, 1896, p. 193.

era in Mexico, which era has left only insignificant traces and these generally not well established; but it is possible also that we shall not have much light in the future, because in truth the modern sediments and our Tertiary eruptives have covered much of our territory, so that if some day Paleozoic areas should be discovered there they would necessarily be very small and perhaps insufficient to tell us the condition of this part of the continent during the Paleozoic era. There is in Mexico, for the same reason, much uniformity of location of the formations actually known, and it is not, then, to be wondered at that we must consider all these evidences in interpreting the tectonic scheme which contributes to the general forms of Mexico.

LOWER CALIFORNIA.

According to the conclusions of J. M. Ramos,[a] set forth in a succinct geological study of the region of Calamahi, north of San Ignacio, in the central part of Lower California, there exists near parallel 29° a relatively narrow band which this author refers to the Primitive or Archean formation, this band consisting of crystalline schists, especially mica schists. Among the samples brought by the exploration commission we have later recognized, in addition to mica schist, biotite gneiss, gneissic granite, and some granites with white mica. These rocks were found in a sierra a little distance from the Gulf of California, which appears to form a border of a relatively high tableland, including the valley of San Ignacio. In the center of this valley and on the sides of a steep coastal sierra, the rocky slopes of which extend to the waters of the gulf, Ramos says that the granites stand out above the schists as islands. These schists show advanced erosion, in contrast with the masses of the granite, which are of greater relief, owing to their better resistance to erosion. Near Calamahi, on the mountain of Martinica, Ramos found a series of wedges of granite traversing the mica schists. The crystalline rocks of Calamahi are hidden in places under the Tertiary rocks and disappear completely toward the west, not only beneath these rocks but chiefly beneath Tertiary marine sediments which extend to the coasts of the Pacific, and even to the foot of the coastal sierra of the gulf.

Everything goes to show that a large part of the peninsula was submerged at the end of the Tertiary and even at the beginning of the Pleistocene.

Among the crystalline schists of Calamahi appear numerous dikes of pegmatite with garnet and tourmaline, micaceous rocks (muscovite), etc.

Gneissic biotitic granite is generally found, but we are able to say nothing in regard to its position. It appears to us that the masses

[a] Ramos, J. M., Informe de los trabajos ejecutados por la Comisión exploradora de la Baja California, Tip. Sec. Fomento, Mexico, 1886, p. 76 et seq.

of granite are very ancient, forming for the most part large intrusions and dikes. In this region there appears to be more variety in the granite rocks than in the crystalline schists, which are reducible properly to two types, mica schist and gneiss. The real extension of the so-called Archean formation of the central part of the California Peninsula is unknown to us, but judging from the studies of Emmons and Merrill [a] to the north and south of parallel 30° the granitic rocks and the metamorphic slates continue in the sierra which follows almost parallel to the gulf coast.

In the southern region of the peninsula, near the cape, Eisen [b] marks on his geological map a considerable outcrop of granite rocks, and Castillo,[c] in his geological map of Triunfo, indicates gneiss and mica schists which he considered as very ancient. Emmons and Merrill do not name any age for these metamorphic rocks north of parallel 31°, but if the sierra which they form is a prolonged region of that of Calamahi we would venture to declare them Archean, very much eroded and cut by numerous granite intrusions and other rocks of a later age.

It is possible that the little patches of metamorphic rock which Lindgren [d] describes in the regions to the east of Todos Santos, where he found them very much cut up by granite, may be Archean.

SONORA AND SINALOA.

Passing now to the State of Sonora, Aguilera [e] found Archean rocks principally in the district of Hermosillo and in the district of Altar, likewise cut by numerous granite masses. Dumble [f] has seen mica slates with bands of more quartzose rocks in hills not very far to the north of Alamos, which are considered by him as probably Archean. It has been questioned whether these slates, referred to by Dumble, are so ancient.

In Sonora there are many regions where there exist in small patches crystalline schists and granites, pegmatites, diorites, etc., of an age much later than the schists above referred to. The supposed Archean areas of the districts in the north of the State of Sinaloa are little known to us, so that we can not express any idea as to their petrography or extension.

[a] Geological sketch of Lower California: Bull. Geol. Soc. America, vol. 5, 1894. The profile given by these authors shows very clearly the importance of having there the metamorphic rocks.

[b] Explorations in the cape region of Lower California in 1894: Proc. California Acad. Sci., 2d ser., vol. 5, 1895.

[c] Castillo, A. del, Plano geológico y minero del Triunfo y San Antonio, revisado en 1889.

[d] Lindgren, Waldemar, Notes on the geology of Lower California, Mexico: Proc. California Acad. sci., 2d ser., vol. 1, 1888.

[e] Aguilera, J. G., Bosquejo geológico de México: Bol. Inst. geol. México, Nos. 4, 5, 6, 1896, p. 194.

[f] Notes on the geology of Sonora, Mexico: Trans. Am. Inst. Min. Eng., vol. 29, 1899.

JALISCO.

In the State of Jalisco, on the western flanks of the great sierra, which bounds to the west the valley of Mascota, fronting the coasts of Tomatlan, in the mining region of Desmoronado, there exists a vast granite formation intruded into the crystalline schistose mass, especially the mica schists, under a heavy covering of quartzite. These rocks we have considered provisionally as Archean.

GUERRERO.

Let us now undertake to give a general idea of the complex crystallines of the southern region of Mexico, where, as we have said, the Archean rocks occupy a greater surface area. It has been seen that they are here extended as a belt or zone covering the coastal districts of Guerrero and Oaxaca and that they extend to the southern part of the State of Puebla.

We have seen that the Archean band or zone in Guerrero begins in a relatively narrow area in the district of Galeana, in the State of Guerrero, to the northwest of Petatlan, and follows without any break along the coasts of Acapulco, of San Marcos, and of Jamiltepec, in the State of Oaxaca; it continues through Puerto Angel and the Isthmus of Tehuantepec, and along the coasts of Chiapas. In Galeana the zone of crystalline slates is less than 20 kilometers in width; however, in the district of Tabarez, near Acapulco, it becomes in places 80 kilometers wide.

Elsewhere[a] we have described briefly the crystalline rocks of the slopes of the Sierra Madre del Sur near Tecpam, about 100 kilometers northwest of Acapulco. These rocks are found up to an altitude of 450 meters above sea level, being extended in a zone between the heights of the sierra formed of the modern rocks and the recent formation of the plains of the coast, through which they appear in the hills near the seashore, consisting principally of biotite gneiss, very easily exfoliated, which passes below into a granite gneiss and in places almost to a true granite.

The biotite gneiss is changed rarely into muscovite gneiss, and the crystalline rocks are crossed by dikes, which run in all directions. These dikes are of quartz, of pegmatites with large crystals of rosy feldspar, of micro-granite, and lastly of green dioritic rocks, which are the most recent.

As in other places, the crystalline rocks are here broken by great masses of intrusive rocks (granites and diorites), extending much above the very denuded formation of the slates.

[a] Un voyage à la Sierra Madre del Sur: Mem. Soc. cient. A. Alzate, vol. 14, Mexico, 1899–1900, pp. 159–173.

Here the crystalline schists, although covering a very large zone, are not much varied, since most of them may be classed as biotite gneiss, which passes to granite and very rarely in places to mica schist.

The Archean schists of Acapulco show similar simplicity. These we have examined and described in a study, unfortunately not published, undertaken some years ago by the Institute of Geology,[a] from which we extract some paragraphs:

The studies made on the interoceanic profile between Acapulco and Vera Cruz gave us the opportunity to examine with considerable detail a line practically transverse to the Sierra Madre del Sur—that is to say, in a direction southwest-northeast, thus obtaining a good idea of the structure of this sierra.

As we have already said, the Archean rocks constitute part of the basement of this sierra and are crowned throughout by more recent rocks—in some places Mesozoic sediments and in other places eruptive Tertiary rocks. There are likewise ancient granite masses, which are in evidence particularly in the structure of the high mountain ridges. This granite, as outlying abutments, is found very close to the sea, changing somewhat the general physiography of this sierra. There is, indeed, a very marked contrast between the series of low hills formed of Archean schists which border the sandy beaches or the base-level of the coast and the high mountain ridges of granite which are raised here and there, breaking the general real elevation of the crystalline belt at the foot of the sierra.

The Bay of Acapulco, in the shape of a bottle, is formed by the high mountain ridges of granite, lapped by the waters of the sea on the outer sloping sides which surround it.

At the entrance of the Bay of Acapulco the point of the mountain of Caravali, with a height of 900 meters, towers above the surrounding circle of mountains. Linked to this mountain is a chain of granite and diorite ridges which advance to the summit of the Sierra Madre del Sur, inclosing within themselves different lateral valleys in the form of a horseshoe, very similar in contour to the Bay of Acapulco, which has suggested to us the idea of considering the bay as a submerged valley, which indeed can be proved by the study of the contour lines below the waters of the ocean.

Submerged valleys similar to that of Acapulco have been observed along the Pacific shores, demonstrating that there has probably been a general submergence the whole length of this coast. It is possible to prove movements of actual submersion in various parts of the coast of southern Mexico.

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[a] Aguilera, J. G., Boese, E., and Ordoñez, E., Pérfil geológico de Acapulco á Veracruz, 1900.

On both sides of the chain of mountains connected with those of the Bay of Acapulco the crystalline schists extend for a great distance, represented particularly by biotite gneiss, which pass downward near the shore and on the slopes of Sierra de Acapulco to a gneissic granite, while toward the interior, on the slopes of the heights of the Sierra Madre, there are intercalated thin beds of muscovite gneiss. While the crystalline schists have various folds, it appears that the main body of the formation has an inclination toward the north, or a little deviated to the northeast or to the northwest. About 50 kilometers from the beach toward the banks of the river Papagallo, which crosses the highway of Acapulco, this inclination of the slates is seen. Here they are not biotite gneiss, but a series of green schists, leafy sericitic and chloritic rocks, to which the gneiss changes gradually until it predominates a little farther in the interior at the mountain of Macho, near Tierra Colorada, with a thick formation of mica schist, which in this hill rests against a very ancient granite.

OAXACA, PUEBLA, AND CHIAPAS.

The biotite gneiss, the schists which rest upon it, and the mica schists of the upper part continue with analogous characteristics along the Archean belt to the east toward the State of Oaxaca, where the petrographic character of the formation greatly changes, but we are not yet able to judge of the true importance of each type of schist; nor can we determine the real order of succession, because it is very difficult to follow the series in its true order on account of the advanced wasting by erosion and the complicated and numerous stratigraphic accidents which the great crystalline mass shows.

Aguilera found recently, on the road from Oaxaca to Puerto Angel, the crystalline complex not much diversified, being reduced to some few types of gneiss, crossed by dikes and intrusive rocks of the class of biotite granite and diorite, while Felix and Lenk,[a] while surveying the road between Ejutla and Miahuatlan, also in the State of Oaxaca, saw (in order of succession, commencing with the most ancient) muscovite gneiss (which is of little importance in Guerrero), graphitic gneiss, and pyroxene gneiss. In some other places of Oaxaca these authors find different successions of the crystalline complex, or local exposures of pyroxene, graphitic amphibole, and biotite gneiss.

Girault[b] found graphitic gneiss and biotite gneiss with intercalations of lenses and layers of beautiful crystalline marble, with amphibole mica and pyroxene (cipolina), between Etla and San Miguel de las Peras and in regions not far from those examined by Felix and Lenk.

[a] Beiträge zur Geologie und Palaeontologie der Republik Mexiko, pt. 2, 1899, pp. 158–159.
[b] Informe de la zona minera de San Miguel de las Peras: Bol. Agr. y Min., October, 1892.

In all this region of Guerrero and Oaxaca, where the Archean formation acquires the greatest extension, the granitic rocks are always prominent, appearing in all places as the skeleton or the resistant frame, which the effects of the erosion on the schists have caused to be towering. Such masses, rising in the midst of the fields of Archean schist, differ in age and in lithological character.

There are granitic masses so ancient that they can hardly be separated from the Archean rocks, and it might even be thought that these form the base of all the formations. Such, for example, are the alkaline and perthitic granites of the Sierra de Acapulco, which appear to have been much disturbed, the same as the schists. This granite contains intrusions or, more exactly, segregations of green dioritic rocks similar to those which are seen in the ancient granites of Ascutney Mountain, described by Daly.[a]

The perthitic granite takes on a schistose appearance (gneissic granite) and afterward passes into a true gneiss.

Very ancient granite can likewise be identified in some regions of Oaxaca, as in the district of Ejutla and Puerto Angel and in the Isthmus of Tehuantepec.

More recent granite rocks crossing the Archean rocks are very numerous and diversified. We may mention here as most abundant biotite and pyroxenic granites, granite diorites, diorites, and some porphyrites and felsites.

The dikes in the Archean rocks are very abundant, although not of great thickness. In order of age—since some are crossed by others—we may cite pegmatite dikes with garnet, with white mica, or with black tourmaline, dikes of pure quartz, and dikes of a green aphanitic rock of a heterogeneous composition.

We have already mentioned the fact that up to the present time there has been no identification in Mexico of the Paleozoic rocks resting directly upon the Archean rocks.

From what we have seen thus far it appears that during the Paleozoic era a large part of the Archean rocks were emerged and exposed to destructive erosion. Only in the south of Mexico, in the State of Chiapas, Sapper[b] found Carboniferous formations and probably Devonian. In almost all parts of the slopes of the Sierra Madre del Sur the Archean crystalline rocks disappeared under the limestone, which is exposed in massive bands and which more than once has been referred to the Cretaceous, but this determination of the age of the limestone must yet be proved in many places.

These Mesozoic rocks appear to rise toward the sierra from the coast, first as small patches crowning the mass of the granite, in part

[a] Daly, R. A., Geology of Ascutney Mountain, Vermont: Bull. U. S. Geol. Survey No. 209, 1903. Mechanics of igneous intrusions: Am. Jour. Sci., 4th ser., vol. 15, 1903.

[b] Op. cit.; also Sobre la geografía física y la geología de la península de Yucatán: Bol. Inst. geol. de México No. 3, 1896.

still covered with the crystalline schists, afterward as foothills, and at last very abundant, disputing with the eruptive rocks the preponderance in the structure of the Sierra Madre, or, to put it better, the complicated aggregate of sierras which covers all of the southern part of the Republic.

A completely distinct phase is exhibited by the extensive group of crystalline schists, considered provisionally by us as Archean,[a] which appear principally in the southern part of the State of Puebla, in the districts of Chietla and Acatlan. The formation of Acatlan, which can be well studied on the banks of the river of that name, consists at the base of augen gneiss of a dark color, upon which rests a mass of green schists, very diversified and much exfoliated and subjected to very frequent foldings and dislocations.

Even though there were no connection between these crystalline slates of Acatlan and the Archean slates of the coast belt, it would still appear to us that the Acatlan formation can belong to a division more recent or to a higher member of the Archean. As we have already said, this opinion should be later corroborated.

Upon the crystalline rocks of Acatlan rest patches of sedimentary Triassic beds and the Cretaceous limestone, and they in turn are hidden by recent eruptive rocks.

In closing this summary enumeration of the classes of rocks that make up our Archean formation, we may cite the observation which Dr. E. Böse has been kind enough to communicate to us, taken from his work on the geology of the Isthmus of Tehuantepec,[b] which is now being printed.

Böse divides the isthmus into three regions—the plain of the gulf coast toward Coatzacoalcos, the sierra of the center, and the plain of the Pacific coast toward Tehuantepec. The crystalline schists are found exclusively in the last region and extend as far as the slopes of the central sierra.

The slates constitute a true complex, in that Böse was not able to discover the proper relation of superposition nor the stratigraphic features, as much on account of the effects of erosion as from the fact that they appear exposed only in isolated sections because of the recent sediments which cover them. The slates lie oriented in all directions and with diverse inclinations. The crystalline complex of Tehuantepec appears to present types of slate similar to those of the region of Ejutla and Miahuatlan, chiefly biotite gneiss, amphibole gneiss, mica slate, green chloritic schist, muscovite gneiss, etc.

In contact with the schists are gneissic granites, and between the masses which are exposed in the plain of the coast are found perthitic granite, perhaps as ancient as that of Acapulco, biotite granite, dior-

[a] Pérfil geológico de Acapulco á Veracruz.
[b] Reseña acerca de la geología de Chiapas y Tabasco: Bol. Inst. geol. de México No. 20.

ites, and various other rocks, some of Tertiary age. These rocks are felsites, quartz porphyries, rhyolites, and andesitic rocks. The limestone, probably Cretaceous, is found resting in thick beds upon crystalline slate in the sierra which passes through the center of the isthmus, in the same manner as in the other regions which we have summarily sketched.

According to Sapper and Böse,[a] the Archean is found represented upon the extreme west of the Sierra Madre de Chiapas by gneiss and some phyllites. Between Dolores and Frontera the sierra is composed of biotite gneiss, while in the valley of Cintalapa there is hornblendic gneiss. Between the narrow bands or belts of crystalline schist which Sapper examined in the sierra there are mica slates in addition to gneiss and schists. Böse thinks it probable that the Archean crystalline slates of Chiapas occupy in reality an area greater than that which has hitherto been supposed.

SECTION 2. NEW MEXICO, INCLUDING PART OF THE FRONT RANGE OF SOUTHERN COLORADO.

SUMMARY OF LITERATURE.

Wislizenus,[4] in 1848, states that granitic rocks prevail in the mountains about Santa Fe and for some distance to the south. These are associated with porphyry and trap.

Blake,[5] in 1856, describes ridges of metamorphic slate in the Santa Fe Mountains, upon the edges of which rest horizontal Carboniferous strata.

Loew,[6] in 1875, states that the mountains between Santa Fe and Las Vegas contain Azoic rocks which are chiefly granite and syenite. At Santa Fe Creek gneiss is accompanied by Primitive clay slate and syenite. Veins of fine-grained gneisses occur in a coarse aplite or granulite also intersected by syenite seams.

Gilbert,[7] in 1875, describes the range region of western New Mexico and eastern Arizona. Northwest of the Burro Mountains for 50 miles are islands of Archean and Paleozoic rocks. The most conspicuous of the former is a deep-red granite. In the Santa Rita Mountains the axial rocks are Archean schists. On the eastern border of the Plateau region is a chain of ranges which coalesces with the Rocky Mountains of Colorado and consists mainly of Archean and Carboniferous rocks. The whole front of the Sandia Mountains except the crest is Archean.

St. John,[8] in 1876, describes the Black Mountains as a lofty granite barrier. The upper canyon of the Cimarron is composed of granitic rocks, with which are associated micaceous schists and hard quartzose rocks. In the Raton Hills are granitic igneous rocks, the relations

[a] Loc. cit.

of which to the Tertiary are not easy to make out. The Vermejo Mountains have a nucleus of massive metamorphic rocks.

NEWBERRY,[9] in 1876, states that in the Santa Fe Mountains is found coarse red granite, characteristic of the central portion of the Rocky Mountain system. The Carboniferous strata rest directly upon the granites. The central axis of the Nacimiento Mountain is composed of a similar massive red granite, upon the slopes of which rests the Carboniferous formation, for the most part limestone, in many places nearly vertical, yet but slightly metamorphosed.

STEVENSON,[10] in 1879, describes a continuous Archean area on the western side of the district running from Spanish Peaks south. It forms the axis of the Culebra Range, continues through the Taos and Mora ranges, and passes into the Cimarron Range. The Santa Fe and United States anticlines show Archean rocks which are separated from the main area. The rocks show great uniformity in character, including gneissoid granite, gneiss, and mica schist as the predominant types.

STEVENSON,[11] in 1881, gives a systematic account of the Archean rocks of southern Colorado and northern New Mexico. Four areas are seen within the district. The most western marks the course of the Santa Fe axis; the second, that of the Culebra-Mora axis, and the third and fourth that of the Cimarron axis. The rocks in the Santa Fe axis are gneiss, mica schist, which resembles sandstones, and granite. South of the Santa Fe road are numerous exposures of an exceedingly coarse granite or granite conglomerate. With this are many beds of almost black gneiss, holding beds of snow-white quartz. The Culebra-Mora axis varies in width from 5 to 25 miles. It includes granite, gneissoid granite, micaceous and hornblendic schists, and quartzites. Compact gneiss, quartzite-like in character, is found in the main canyon of Costilla Creek. Bands of quartzites are found on Comanche Creek, the north fork of Moreno Creek, in Costilla Creek range on Coyote Creek, and in the vicinity of Santo Nino on Cebolla Creek. These are sometimes found in gneissoid granite and sometimes in mica schist. The granite below the junction of the forks of Moreno Creek is very coarse and resembles conglomerate. The rocks of the Cimarron axis include mica schist, coarse granite, and gneiss sometimes resembling quartzite. The dips of the Archean rocks are much confused, and the distortion at most localities is so great that neither the succession of the strata nor the general structure could be made out during the brief examinations. Positive proof of unconformity to the overlying Carboniferous is not easily obtained, the main obstacle in the way of making the determination being the character of the rock. Usually the disturbance near the junction of the two series is very violent, and the rate of dip changes greatly within a short distance, sometimes becoming even reversed.

But distinct unconformity may be asserted as existing in the vicinity of Costilla Peak, where the enormously thick Carboniferous series terminates abruptly against the Archean core of the Cimarron axis. No absolute evidence exists to settle the age of these rocks. Lithologically they bear a close resemblance to the Laurentian series of the east, and at more northern exposures within the Rocky Mountain region they have been referred by all observers to that age. The coarse gneissoid granite, or granite conglomerate, immediately underlying the Carboniferous at many localities may possibly be of somewhat later origin.

KEYES,[12] in 1905, discusses the fundamental complex beyond the southern end of the Rocky Mountains in New Mexico. Most of the extensive formations composed of granites, schists, and gneisses, which form the axial foundations of so many of the mountain ranges of the region, are now believed to be of much later geological age than is generally understood to be covered by the title Azoic or Archean. Criteria are discussed for the separation of the Archean and Proterozoic rocks, and emphasis is placed on the sedimentary origin of the Proterozoic as a criterion for its separation from the Archean. Brief descriptions are made of the crystalline rocks of the Culebra, Taos, Cimarron, Las Vegas, Mora, Santa Fe, Placer (Ortiz), Nacimiento, and Jemez mountains, the Zuni dome, the Sierra Oscura, the San Andreas, Organ, Caballos, and Santa Rita mountains and the Mogollon uplift.

LINDGREN and GRATON,[13] in 1906, as a result of a reconnaissance of the mineral deposits of New Mexico, state that the northern half of the central mountain belt—the Mora, Taos, and Santa Fe ranges—is composed largely of ancient crystalline rocks, which can without hesitation be assigned to pre-Cambrian time. The cores of most of the ranges which constitute the southern part of this belt, such as the Sandia, Magdalena, Caballos, and Franklin mountains, are likewise composed of these rocks, as are also some of the ridges in the desert-range province, for example, the Burro Mountains. Red and gray gneisses, which represent sheared granites, are most abundant, although many of these rocks are only a little foliated, and much massive granite is present. Dikes and other intrusive bodies of diorite, gabbro, diabase, etc., have in most cases suffered sufficient shearing and mineral alteration to be converted into dark schistose rocks, which may be grouped together as amphibolite. Extreme foliation of the granitic gneisses frequently results in the production of quartz-sericite schists, and less commonly quartz-biotite schists. Some sedimentary rocks, such as quartz-pebble conglomerates, sandstones, shales, and limestones, also enter into the pre-Cambrian complex and have been metamorphosed more or less completely into schists. Dikes of pegmatite and aplite cut many of these foliated rocks, but are themselves pre-Cambrian.

SUMMARY OF PRESENT KNOWLEDGE.

The present state of knowledge of the pre-Cambrian of this region is covered in the preceding summary by Lindgren and Graton.

SECTION 3. ARIZONA AND ADJACENT PARTS OF NEVADA.

SUMMARY OF LITERATURE.

POWELL,[14] in 1874, states that below the Carboniferous are sedimentary rocks provisionally called Devonian and Silurian. Still underlying these is an extensive series of metamorphic crystalline schists, in some places yet showing faint traces of the original stratification, but usually these are so degraded that the total thickness of the beds was not determined. In places they constitute about a thousand feet of the altitude of the walls. These beds are traversed by dikes of granite, and beds of granite are found which are believed to be intrusive, hence of igneous origin. In some places the evidence is complete. An extensive period of erosion separates these schists and granite from the overlying Silurian and Devonian rocks.

In the Grand Canyon are the records of an extensive period of deposition in the schists, followed by plication, erosion, fissuring, and eruption. Again we have an invasion of the sea, which remains until 10,000 feet of shales, sandstones, and limestones are deposited; and this is followed by a dry-land period, marked in some places by at least 10,000 feet of erosion and accompanied by plication, fissuring, and eruption.

POWELL,[15] in 1875, further describes the Grand Canyon group. Unconformably below the Carboniferous of the Kaibab Plateau is a middle series of slates, sandstones, and limestones 500 feet thick, so inclined that the total thickness of its beds is 10,000 feet. Below these are, unconformably, a thousand feet of crystalline schists with dikes of greenstone and beds of granite. This lower series is composed chiefly of metamorphosed sandstones and shales, which have been folded so many times, squeezed and heated, that their original structure as sandstones and shales is greatly obscured or entirely destroyed, so that they are metamorphic crystalline schists. After these beds were deposited, folded, and deeply eroded they were fractured, and through the fissures came floods of molten granite, which now stands in dikes or lies in beds.

GILBERT,[16] in 1875, describes the axis of the Black and Colorado mountains in northwestern Arizona as consisting of granitoid rocks and highly crystalline schists. In Bowlder Canyon of this range upon a nucleus of syenite are plicated crystalline schists. In Virgin Canyon the nucleus is gneissic, with a general anticlinal structure. In Black Canyon the nucleus is a homogeneous rock resembling pegmatite, but is probably metamorphic.

In the Grand Canyon of the Colorado the Tonto sandstone rests directly on plicated and eroded schists and associated granites, and demonstrates them to be pre-Silurian. Farther down the river the same relation is seen in the Virgin Range; and in the next ridge to the west, through which the river has cut Bowlder Canyon, are gneisses so similar to those of the Virgin Range that they may safely be classed with them. In Music Mountain, in the Black Hills near Prescott, and on Canyon Creek, or, more generally, all along the southwestern border of the Plateau region in Arizona, the Archean schists and granites are seen beneath nonconforming members of the fossiliferous rocks, usually the Tonto sandstone. To the south and west of this line stretches a great ocean of metamorphic ridges in which no one has found fossils.

Gilbert, in 1875, describes the range region of eastern Arizona and western New Mexico, principally the latter. See summary under section 2, New Mexico, page 768.

Marvine,[17] in 1875, states that granite is found below the Tonto sandstone at the mouth of Grand Canyon, at Music Mountain, and in the canyon of New River. At Truxton and on the road southwestward granite occurs in the hills, often lava capped; is found at Cross Mountain, near Fort Rock; at Aztec Pass; at Juniper Mountains; between Prescott and Agua Fria Valley, and in the Black Hills. In the Juniper Mountains there are also found highly metamorphic rocks, as schists, slates, etc., often covering considerable areas and with which many of the silver and gold bearing lodes of the country are associated. At Camp Verde on the Verde River sedimentary rocks rest upon syenites. The Tonto sandstone rests upon the granite in the Sierra Ancha, in the San Carlos Valley, and in the Apache Mountains. The main mass of the Pinal Mountains is granite, but upon their northeast flanks is a long area of highly metamorphic rocks, consisting mostly of crystalline schists, micaceous, chloritic, and talcose, their erosion forming an intricate maze of small valleys separated by sharp ridges, which present a strong contrast with the more massive features of the mountains. The granites and schists of the Pinal Mountains extend along Pinal Creek to Camp Pinal.

Powell,[18] in 1876, further describes as unconformably below the Tonto sandstone the Grand Canyon sandstones, shales, and limestones, 10,000 feet in thickness; and below this the Grand Canyon schists, of undetermined thickness, composed of hornblendic and micaceous schists and slates, associated with beds and dikes of granite. The Grand Canyon group rests unconformably upon the crystalline schists. The plane of demarcation separating this group from the Tonto group is very sharp. Fossils have been found at the base of the Grand Canyon series, but they are not well preserved, and little can be made of them. Still, on geological evidence, these beds are considered Silurian.

WALCOTT,[19] in 1883, describes a great series of unconformable sediments below the Tonto, which are divided into two groups, the Chuar and the Grand Canyon, between which there is an unconformity by erosion. The lower or Grand Canyon group is made up of an immense mass of sandstones and interbedded greenstones, and the Chuar group is a series of sandy and clay shales. The Archean at the base of the Grand Canyon group consists of thin-bedded quartzites broken by intrusive veins of a flesh-colored granite, the layers of quartzite standing nearly vertical. The Grand Canyon and Chuar groups unconformably deposited over the underlying Archean are referred to the Lower Cambrian and placed as the stratigraphic equivalent of the Keweenawan group of Lake Superior. In the Grand Canyon series are found a few obscure fossils. The Chuar and Grand Canyon series are both wholly unmetamorphosed and but slightly disturbed.

WALCOTT,[20] in 1886, states that the Tonto sandstone of the Grand Canyon district is Upper Cambrian or Potsdam. Then below occurs a great unconformity by the erosion of an entire cross section of 13,000 feet of strata of the Chuar and Grand Canyon series; below, the unconformable series rest unconformably on underlying highly inclined strata, which where the section terminates belong to a system of strata between the Grand Canyon series and the Archean. On account of this great unconformity below the Tonto it is thought better to classify all the pre-Tonto strata as pre-Cambrian, middle and lower Cambrian times being in the Grand Canyon district a period of erosion. The Chuar formation, or upper 6,000 feet of limestones and argillaceous shales, lithologically resembles the Trenton limestone and Utica shales of the New York section. There is no evidence of the great age of these strata in their physical aspect. The lower 6,000 feet of Grand Canyon formation are sandstones with interbedded lava flows toward the upper portions. Ripple marks and mud cracks abound in many of the layers, but not a trace of a fossil was seen. Midway in the lower portion of the overlying Chuar strata the presence of a fauna is shown by a minute discinoid or patelloid shell, a small *Lingula*-like shell, a species of *Hyolithes*, and a fragment of what appears to have been the pleural lobe of the segment of a trilobite belonging to a genus allied to the genera *Olenellus*, *Olenoides*, and *Paradoxides*. There is also an obscure Stromatopora-like form that may or may not be organic. The fauna as given above is very unsatisfactory, but it shows the presence of a fauna that is Cambrian in character, as far as we know, although it may be a trace of a fauna preceding that of the Lower Cambrian of the Atlantic border; and as the stratigraphic evidence favors this view, it is thought that it can not be considered of Cambrian age.

WALCOTT,[21] in 1889, refers the section laid bare in the Grand Canyon of the Colorado to the Keweenaw group. This section presents one of the best opportunities known to the author for the discovery of a pre-*Olenellus* fauna.

WALCOTT,[22] in 1890, gives the Algonkian section of the Grand Canyon as follows: Chuar (shales and limestones), 5,120 feet; Grand Canyon (sandstones with lava flows in upper part), 6,830 feet; Vishnu (bedded quartzites and schists), 1,000 feet.

WALCOTT,[23] in 1894, gives the results of his study of the Algonkian rocks of the Grand Canyon of the Colorado. The following classification of the rocks is adopted:

Cambrian: Tonto.
  Unconformity.
Algonkian: Grand Canyon { Chuar. / Unkar.
  Great unconformity.
Algonkian (?) Vishnu.

The Vishnu at the one point examined, due south of Vishnu's Temple, consists of micaceous schists and quartzites, cut by dikes and veins of granite. The Unkar terrane, 6,830 feet thick, consists of limestones, sandstones, conglomerates, and intrusive and extrusive basic rocks of various kinds. The basal conglomerate is formed largely of pebbles derived from the upturned edges of the pre-Unkar strata. The Chuar terrane, 5,120 feet thick, consists mainly of shales of various kinds, but contains 285 feet of limestone. Resting unconformably upon the Grand Canyon series is the Tonto Cambrian. Before the deposition of the latter the Grand Canyon series was planed to a base-level and all the strata of the series were truncated.

The entire Grand Canyon series is placed in the Algonkian period or Proterozoic era. Various possible correlations of the Grand Canyon with other series may be made, but it is evident that until characteristic fossils are found in the various terranes now referred to the Algonkian it will be impossible to make any correlations that will be more than tentative suggestions.

VAN HISE,[24] in 1907, observed the pre-Cambrian rocks of the Grand Canyon of the Colorado. The Unkar series consists of conglomerates, cherty limestone, shales, slates, and indurated sandstones approaching quartzites. The lower part of the series, that below Red Canyon Creek, consists from the base upward of a persistent conglomerate bed, in which greenish cherty limestone 30 to 50 feet thick predominates; above this a very considerable thickness of rock in which dark-colored cherty limestone 50 to 75 feet thick predominates; and above this sandstones and shales. The pebbles of the conglomerate comprise the greatest variety of granites, gneisses, and schists, and also numerous ones of quartzite. This must mean that somewhere is a pre-Unkar sedimentary series from which the quartzite was derived. No such quartzite is known nearer than the Uncompahgre Mountains of southwestern Colorado. In Red Canyon intrusive diabase or basalt was observed in the lower portion of the Unkar terrane. The Unkar series rests upon the truncated edges of the Archean in its typical development.

The Archean, notwithstanding the great variety of rocks which compose it, seems to have been almost absolutely base-leveled, at least for the district where we saw it. The contact between the conglomerate and the Archean is regular, as the bedding of the Unkar seems to be absolutely parallel with it. Various measurements of the dip of the contact plane of the Unkar beds were taken, the results ranging from 10° to 12° NE. The descriptions written for the Lake Superior Archean in Bulletin 86 will apply exactly to the Archean of the Grand Canyon. Black hornblende gneiss and light-colored gneissoid granite are abundant. In many cases these are interlaminated. In some places the gneisses are distinctly banded; in others they are distinctly foliated or schistose. The gneisses are cut by various granites in the most complex manner, and great exposures show the dikes ramifying and coming together in the most fantastic manner. This indicates that before the granites were intruded the old gneisses had been most completely deformed. None of the granite dikes penetrate the Unkar. Dark-colored gneisses seem to be the oldest rocks of the series.

The great Grand Canyon group, as a result of its gentle dip to the northeast of 10° or 12°, has had its entire thickness truncated. At one place the two unconformable planes already described come together at an angle of 10° or 12°, the inclined plane being that between the Unkar and the Archean. It is perfectly clear that the Archean in all its complex parts and the Unkar have behaved as a unit in the deformation, being tilted together at the gentle angle described. Both old and new, weak and strong, simple and complex, have been gently inclined 10° or 12°, with comparatively little differential movements within the mass.

Resting unconformably upon the Archean and the Unkar is the Tonto sandstone. The latter is horizontal, and is seen for miles to lie upon the same uneven surface of the two previous formations. The plane between the Tonto and the underlying formations has not the same marvelous evenness as that between the Unkar and the Archean.

Blake,[25] in 1899, refers to the Archean the thick layers of gneiss forming the southern flank of the Santa Catalina Mountains in Arizona. The gneiss is in flat layers representing beds. A part of it is augen gneiss; other layers are quartzose and seemingly quartzites.

DAVIS,[26] in 1900, in a general account of a trip through the Colorado Canyon district, briefly describes certain features of the pre-Cambrian geology. He calls attention to the extraordinary evenness of the floor of schists, with granite dikes (Archean), upon which the Chuar and Unkar terranes (Algonkian) rest. The floor for the Paleozoic strata is somewhat less regular than the floor for the Unkar. In two places the pre-Cambrian rocks rise higher than the basal Tonto (Cambrian) sandstone. The Archean schists beneath the Unkar have a steep and regular slope, indicating uniform resistance to erosion. Where, beneath the Tonto, they show a bench, it is taken to indicate a softer character at this point, probably due to a longer period of pre-Tonto weathering.

COMSTOCK,[27] in 1900, reviews the stratigraphy of Arizona.

BLAKE,[28] in 1901, describes the salient features of the geology of Arizona. The Santa Catalina, Rincon, and Rillito mountains consist largely of granitic gneisses and schistose rocks of pre-Cambrian age, with a highly complex folded structure, and exhibiting a high degree of metamorphism. Taken together, these mountains may be regarded as the main axis of ancient uplift and of insular land areas in the pre-Cambrian and Paleozoic periods, the beginning of the "Arizona Land."

The gneiss of the southern side of the Santa Catalina near Tucson is regarded as Archean. It is remarkable for its regularity of stratification and its great thickness, probably more than 10,000 feet. It occurs in great tabular masses made up of thin layers, which when seen laterally give the appearance of evenly stratified shales and sandstones. In the same range, but on the northeastern side, facing the valley of the San Pedro, another formation of thinly bedded and highly crumpled mica schist in sharply defined zigzag folds is referred to the Huronian, and is given the name Arizonan.

RANSOME,[29] in 1904, describes, in the Pinal Mountains of the Globe district of Arizona, mica schists with occasional bands of amphibole schists, which he calls the Pinal schists. These are intruded by quartz, mica diorite, and granite. The schists and intrusives are unconformably below a nonfossiliferous series supposedly of Cambrian age. The schists are believed to represent metamorphosed arkoses or grits. They are probably to be correlated with the Vishnu series of the Grand Canyon, provisionally called Algonkian by Walcott. In the absence of other criteria the Pinal schists are referred to the pre-Cambrian.

In the Mule Mountains of the Bisbee district, 90 miles to the south, are similar schists, also called the Pinal schists.[a] Evidence of sedimentary origin is less satisfactory than in the Globe district, and

[a] The Pinal schists probably correspond to the Arizonian schists of Blake, Eng. and Min. Jour., vol. 35, 1883, pp. 238–239.

pre-Cambrian granitic intrusives are absent. Here also they are referred to the pre-Cambrian.

Jaggar and Palache,[30] in 1905, map and describe the geology of the Bradshaw Mountains quadrangle, in Arizona. The Yavapai schists, assigned to the Algonkian, are made up of 7,000 feet of schistose sedimentary rocks and schists of igneous and doubtful origin, compressed into isoclinal folds and rendered schistose by a horizontal force acting from northwest to southeast. The conglomerate contains pebbles of granite, quartz, schist, and quartzite, indicating a basement made up of these rocks, but such a basement has not been definitely located within this district. The Yavapai formation is intruded by acidic and basic igneous rocks, plutonics and surface, some of them probably Algonkian and some of them doubtfully Tertiary.

The evidence of the pre-Cambrian age of the Yapavai schists consists in their similarity to certain schists intruded by diorite at Jerome to the northeast, which are overlain by Paleozoic rocks unconformably, and in their similarity with Walcott's lower or Vishnu series of the Grand Canyon district.

Lindgren,[31] in 1903 and 1905, maps and describes the geology of the Clifton quadrangle, in Arizona. The lowest rocks are the Pinal schists, consisting of quartz sericite schists, probably of sedimentary origin, and smaller bands and masses of amphibolitic rock. The schist is intruded by granite of pre-Cambrian age. Resting unconformably on these rocks is the Coronado (Cambrian) quartzite.

Ransome,[32] in 1908, regards the Vishnu series of the Grand Canyon as consisting of fine-grained gneiss cut by red granite, probably of Archean age. This had been described by Walcott as sedimentary and probably Algonkian. The Pinal schists of the range districts to the south, previously correlated with the Vishnu séries because of its supposedly sedimentary character, are now correlated with the Chuar and Unkar series.

SUMMARY OF PRESENT KNOWLEDGE.

The geològical map of Arizona still contains many blanks. The cores of many of the mountain ranges in a general zone trending northwest-southeast through the central part of the State consist largely of granites, gneisses, and schists, probably of pre-Cambrian age. It is likely that with the granite mapped as pre-Cambrian there are included granites of later age. The granites and some of the gneisses are of igneous origin; the schists and most of the gneisses are of unknown origin. Ransome and Lindgren concluded that the Pinal schist of the Globe, Bisbee, and Clifton districts represented metamorphosed arkose or grits, and was to be correlated with the Vishnu "terrane" of the Grand Canyon. A similar conclusion was reached by Jaggar for the basal series of the Bradshaw quadrangle. This correlation, however, was made on a misunderstanding as to the nature of the Vishnu, which had been described by Walcott as a metamorphosed quartzite, but which is now regarded by Ransome as gneiss. Ransome now correlates the Pinal schist with the Chuar and Unkar groups.

In the Grand Canyon there is a basal complex, Powell's "Grand Canyon schists," described by Van Hise as typically Archean or basement complex in aspect, including granites and gneisses in considerable variety, a hard hornblende gneiss being the oldest in the series. Walcott describes this complex as consisting of micaceous schists and quartzite cut by granite, which he finds on the north side of the canyon south of Vishnu's Temple and calls the Vishnu "terrane," doubtfully referring it to the Algonkian. This complex Van Hise did not examine in the locality described by Walcott. Ransome and Lindgren believe that Powell's "Grand Canyon schists," Walcott's Vishnu "terrane," and Van Hise's "Basement complex" are probably the same, and doubt the existence of quartzites. The complex of granites, gneisses, and schists was almost completely leveled before the deposition of the next overlying series. The unconformably overlying series is the Grand Canyon series, 11,950 feet thick, consisting of two groups—the Unkar, 6,830 feet thick, and the Chuar, 5,120 feet thick.

The Unkar group consists of sandstones and limestones interstratified with basalts, and has at its base a conglomerate composed largely of pebbles derived from the upturned edges of the pre-Unkar rocks. Resting upon the Unkar group with a slight unconformity is the Chuar group. It consists of shales, sandstones, shaly limestones, and limestones. In the middle of the lower portion of the shales and limestones of the Chuar group is a sparse fauna, consisting of a minute discinoid or patelloid shell, a small *Lingula*-like shell (which may be a species of *Hyolithes*), and a fragment of what appears to be the pleural lobe of a segment of a trilobite belonging to a genus or allied to the genera *Olenellus*, *Olenoides*, and *Paradoxides*. There is also a Stromatopora-like form that is probably organic. Resting with a great unconformity upon the Chuar are the strata of the Tonto or middle Cambrian group. During the time represented by this unconformity the sediments of the Grand Canyon series were elevated, faulted, somewhat flexed, and eroded, so that the entire series was cut through, and the area, including the more resistant Vishnu rocks, was base-leveled. The length of time required by this unconformity is believed to be longer than the period of lower Cambrian sedimentation, and the Grand Canyon series is therefore placed in the Algonkian. The Grand Canyon series has lithological analogies with the Keweenawan of Lake Superior and the Llano series of Texas, but there is no certain evidence, in the absence of fossils, by which it can be equated with either.

The fauna of the Chuar group, although so meager, furnishes the largest number of fossils yet found in the pre-Cambrian. While not sufficient to give a basis for correlation, it gives legitimate hope that a more satisfactory pre-Cambrian fauna may be found in the future.

SECTION 4. UTAH.

SUMMARY OF LITERATURE.

UINTA MOUNTAINS.

MARSH,[33] in 1871, states that in the Uinta Mountains is an extensive series consisting of reddish sandstones and quartzites, sometimes metamorphosed and apparently without fossils. The series is referred provisionally to the Silurian on the ground that resting conformably upon it are limestones bearing Carboniferous fossils.

HAYDEN,[34] in 1872, states that in the Uintas from the red beds of the Triassic to the oldest quartzites no unconformity was detected. The whole series has a thickness of 10,000 feet or more; of this the lower 8,000 consists of sandstones and quartzites. Although no fossils were found, the upper part of these 8,000 feet is believed to be Silurian and to pass down without a break to the rocks of Huronian age. The quartzites are like the Sioux Falls, Dakota, quartzites, which are associated with the pipestone referred by Hall to the Huronian. In the Uinta series is an excellent illustration of a gradual transition from unchanged to metamorphic rocks.

POWELL,[14] in 1874, describes in the Uinta Mountains crystalline schists upon which rest unconformable Carboniferous rocks.

POWELL,[18] in 1876, describes the Uinta sandstones, shales, and quartzites, 12,500 feet thick, as resting unconformably below the Lodore group. Again, unconformably below the Uinta sandstone is the Red Creek quartzite associated with hornblendic and micaceous schists, 10,000 feet thick. It is evident that the metamorphism of the Red Creek quartzite is anterior to the deposition of the Uinta group, for the beds of the latter, especially near the junction, are chiefly made up of fragments of the former; hence the unconformity is very great, and the quartzite was a lofty headland in the old Uinta sea—perhaps 20,000 feet high—when the lowest member of the Uinta sandstone was formed. The period of erosion separating the Uinta sandstones from the Carboniferous beds was sufficient to carry away at least 3,000 feet of the former, and how much more can not be said. This unconformity is seen at Whirlpool Canyon and the Canyon of Lodore, the difference of dip between the two groups being from 4° to 6°, and the members of the Lodore group steadily overlapping the upper members of the Uinta and cutting off more than 2,000 feet of the latter. At the Canyon of Lodore the Uinta sandstone also protrudes into the Lodore shales. On the northeast side of Owiyukuts Plateau the Uinta sandstones are seen to disappear, having been cut off by erosion before the deposition of the limestone, and there is from 1,000 to 2,000 feet more of the Uinta sandstone at one end of the ridge than at the other. The unconformity can also be seen in the canyon of Junction Mountain, and has been observed on the south side of the Uinta Mountains in a canyon cut by the tributaries of the Uinta River. It is suggested that the Uinta sandstones may be considered as Devonian—an opinion which would be yielded upon the slightest paleontological evidence to the contrary.

The Red Creek quartzite is believed to be Eozoic. This Eozoic is in large part a pure white quartz, but is intimately associated with irregular aggregations of hornblendic and micaceous schists. These schists were, perhaps, argillaceous strata between the thicker strata of pure siliceous sandstone. The whole group has been greatly metamorphosed, so as almost to obliterate the original granular or sedimentary structure so far as is apparent to the naked eye. Besides the recrystallization, they have been profoundly plicated or implicated, so that it is only in a general way that any original stratification can be observed.

The great mass of the Uinta Range is of the Uinta sandstone. Intercalated with these are shales, argillaceous material, and semicrystalline quartzite; the whole group is exceedingly ferruginous and contains seams of clay ironstone. While weeks and months were spent in the search, no fossils were found in the Uinta group. The Uinta Mountains as a whole have been produced by the degradation of a great upheaved block, having its axis in a general east-west direction. The upheaval is partly a flexed, partly a faulted one, the major part of the faulting and the steeper inclinations being on the north side.

Emmons (S. F.),[35] in 1877, describes the Uinta Mountains as a remarkably simple and regular uplift of an immense thickness of conformable strata, the regularity being disturbed only about a small area of Archean rocks at the eastern end. These old rocks, occurring along Red Creek and covering a comparatively small area, are quartzites, white mica schists, and hornblende schists, with a local development of paragonite beds, and they correspond most nearly to those classed as Huronian in the Rocky Mountains. The beds are steeply inclined and have suffered intense compression and distortion. The general section is that of a double anticline.

On these older rocks are seen the conformably gently dipping Weber quartzites, and the succeeding beds were then deposited around the shores of an Archean island. Above the Archean is a thickness of

10,000 or 12,000 feet of unconformable beds, part of which consists very largely of quartzite and is regarded as pre-Carboniferous, while the upper part is placed in the Upper Coal Measures and Permo-Carboniferous. The Upper Coal Measures are limestones and sandstones and bear fossils; but in the great thickness of lower beds referred to the Weber no fossils are found.

KING,[36] in 1878, describes the Archean rocks of the Uinta Range as a group of pure white quartzites, hornblende schists, and hydromica (paragonite) schist, richly charged with garnet, staurolite, and minute crystals of cyanite. They are referred to the Huronian.

The Paleozoic rocks of the Uintas rest unconformably upon the Archean. They comprise an immense body of quartzites and indurated sandstones intercalated with shales, 12,000 feet in thickness, referred—not, however, without some questioning—to the Weber quartzite or Middle Coal Measures. Directly overlying these is a series of sandstones and limestones having a thickness of 2,000 or 2,500 feet, in which Coal Measure fossils were obtained.

PEALE,[37] in 1879, describes in the Green River district, at station 77, a Cambrian section consisting largely of quartzite and amounting to 7,000 feet. At station 130 is another red quartzite which has a limestone below it, and below them a series of green chloritic rocks unlike those of any other section in the district. The author is inclined to place these below the Cambrian quartzites, and considers them of probably Huronian age. None of these sections expose the underlying crystalline schists.

VAN HISE,[38] in 1889, examined the Archean core of the Uintas. The so-called white quartzite is found to be largely composed of white feldspar. It is thoroughly crystalline, and its lithological affinities are with the granites rather than with the quartzites. The black bands contained in it, supposed by some to represent original layers of a different constitution, and by others to represent dikes, were found to be much altered eruptives. The unconformable contact between the Uinta series and the Archean was seen at many points.

BOUTWELL,[39] in 1902, in the course of a reconnaissance in the western Uintas, found in limestones on the divide between the headward portions of Provo and Du Chesne several lots of fossils indicative of their Lower Carboniferous (Mississippian) age. These limestones appear on broad structural grounds to overlie the great quartzite of the central Uintas. He concludes that this sandstone-quartzite series is proved by fossil evidence to be earlier than Lower Carboniferous, and thus that the interior area of the Uintas is not later than Silurian.

BERKEY,[40] in 1905, discusses the stratigraphy of the Uinta Mountains and suggests a correlation of the basal Uinta quartzite with the basal "Cambrian" quartzite of the Wasatch. The thickness in the western Uintas is 12,000 feet and in the eastern Uintas 14,000 feet. He concludes that the basal quartzite of the western Uintas is surely not "Weber." It is apparently late Cambrian, and possibly in part post-Cambrian, lapping up against the margins of the Paleozoic continent toward the east.

Emmons,[41] in 1907, discusses the stratigraphy of the Uinta Mountains and concludes that the Uinta quartzites are undoubtedly of pre-Cambrian age. They occupy a position corresponding to the pre-Cambrian series in the Grand Canyon, which Powell included under the general name of Grand Canyon series, the lower member of which (the Vishnu) resembles lithologically the Uinta quartzite.

Weeks,[42] in 1907, discusses the stratigraphy and structure of the Uinta Range. He refers the Uinta quartzite formation to the pre-Cambrian and correlates it with the great quartzites of the Wasatch and other ranges of Utah and eastern Nevada, whose position beneath the *Olenellus* shales of the lower Cambrian is generally recognized; also with the pre-Cambrian quartzites of the Grand Canyon. He concludes that no representative of the Basement Complex is known in the Uinta region. The Archean of King, Emmons, and Powell is referred to the upper part of the Uinta quartzite because he has traced certain beds of conglomerate and sandstone, very highly metamorphosed, directly into Quartz Mountain, which was considered by Powell and Emmons to be made up of Archean rocks. Their reference of the series to the Archean was largely due to the great complexity in structure near Green River. Finally he concludes that the Uinta quartzite passes up into the lower shales (Cambrian) without evidence of unconformity, thus differing from Powell, who recognized an unconformity at the top of the Uinta quartzite.

WASATCH MOUNTAINS.

Hayden,[43] in 1872, describes a nucleus of granite in the Wasatch Mountains and on the canyon of the Weber. In Box Elder Canyon are gneisses, quartzites, and slates. In Port Neuf Canyon there are exposed at least 10,000 feet of quartzite, the age of which is obscure, the only thing indicating its position being that Carboniferous fossils are found in the upper horizon.

Silliman,[44] in 1872, regards the granite of Big and Little Cottonwood canyons as probably metamorphic from conglomerates, because it has conspicuous patches of dark-colored material in a light-gray matrix, and because with a glass there can be detected a sort of pebble-like roundness in the quartz of the granite.

Hayden,[45] in 1873, describes syenite in Little Cottonwood Canyon of the Wasatch, at the base of the series, upon which rest feldspathic gneissic strata, and unconformably upon these the lower quartzites. The Wasatch is probably a complete anticlinal fold.

Peale,[46] in 1873, states that the base of the mountains near Ogden is for the most part a red syenite, which passes into granite and gneiss, and contains in places veins of hornblende, quartz, and specular iron. The granites of Cottonwood Creek are conspicuously bedded, the dip being about 50° or 70° to the east, and they contain rounded, pebble-like masses of a dark color inclosed within the gray matrix. These granites are cut by veins of feldspar. The pebble-like masses suggest that the formation is metamorphic.

Bradley,[47] in 1873, regards the core of the Wasatch as metamorphic. The occurrence of angular and rounded patches of dark material in the granite of Little Cottonwood Canyon is taken as evidence that these were pebbles of a conglomerate before its metamorphism. The rocks are chiefly hornblende gneiss and syenite, with quartz veins.

Howell,[48] in 1875, states that in Rock Canyon, near Provo, pebbly chlorite schist is unconformably below hard quartzite.

Emmons (S. F.),[35] in 1877, describes the Wasatch Range as a sharp north-south anticlinal fold over preexisting ridges of granite and unconformable Archean beds, the axis being bent and contorted by longitudinal compression so that at times it assumes a direction approximately east and west. In connection with the folding is a widespread system of faulting and dislocation, in a direction generally parallel to the main line of elevation, which has cut off and thrown down the western members of the longitudinal folds and the western ends of the transverse folds, and they are now buried beneath the valley plains. In the northern region is a second broad anticlinal fold to the east of the main line of elevation. This mountain range occupies the line of former Archean uplift, around which were deposited 30,000 or 40,000 feet of practically conformable beds extending upward from the Cambrian to the Jurassic. At the base of the Paleozoic is the Cambrian formation, which has a small thickness of calcareous slates bearing Primordial fossils and a great thickness of white quartzite, including a few micaceous beds and argillites, the whole being 12,000 feet thick. The granite mass constituting the center of the Wasatch was not protruded through the sedimentary rocks, but the latter were deposited around them, and their present conditions are due to subsequent elevation, flexure, dislocation, and erosion.

In the Cottonwood canyons is a large mass of granite which shows a conoidal structure, and, while massive, has distinct planes of cleavage which dip 50° W. It is a white, rather coarse-grained granite, dotted here and there with round black spots where there has been a concentration of the dark-green hornblende, which is a prominent constituent of the mass. On the western flanks of the Cottonwood granites are some remnants of Archean quartzites and schists, which have a general strike northeast and dip from 45° to 60° W. At the mouth of Little Cottonwood Canyon they consist of a body of quartzites about 1,000 feet in thickness. These quartzites are different from the Cambrian quartzites of Big Cottonwood Canyon; they contain mica in varying quantity, and where this is abundant approach a true mica schist. Toward the mouth of the canyon the mica is replaced by hornblende. Between the Cottonwood canyons are about 2,000 feet of Archean slates, quartzites, hornblende schists, and mica schists. The Cambrian slates above the granites of the Cottonwood stand at an angle of 45°, dipping to the northeast. It is difficult to tell whether the granite should be considered as a part of the main granite body, which it does not resemble very closely, or as belonging with the later outbursts of granite porphyries and diorites which intersect the sedimentary beds of this region. These dikes are very numerous, especially around the Clayton Peak mass and in the region where the mineralization of the beds has been most developed. One of these in the Wasatch limestones is a dike 20 feet wide of syenitic granite porphyry. The Paleozoic beds of the Cottonwood canyons, which fold around and partly cover the granite bodies, have been subjected to intense compression and local metamorphism and cut by intrusive dikes and mineral veins.

The Farmington Archean body is composed of a conformable series of gneisses, mica gneisses, and quartzites, 12,000 or 15,000 feet thick, which dip westerly at about 15° or 20°. The lowest part of the series is coarse and structureless, but it grades up into an evenly bedded rock.

Hague,[35] in 1877, describes the northern Wasatch region and the region north of Salt Lake. The geological structure of the Front Range remains of the same type as to the south, but the Archean rocks are less abundant. In the lower canyon of Weber River are rocks like the Farmington Archean body, which have, however, a westerly dip of 40°. The Cambrian quartzite of Ogden Peak lies unconformably on the edge of the Archean beds. In Ogden Canyon the quartzite is occasionally conglomeratic, containing pebbles of quartzite and jasper. These pebbles are sometimes flattened and elongated in almond-shaped bodies, and are frequently distorted and banded into curious forms. Sometimes two or more pebbles are pressed together so as to form apparently one mass. The flattened pebbles appear with their longer axes in parallel planes.

King,[36] in 1878, states that on the west side of the Wasatch is a fault which has thrown the layers downward from 3,000 to 40,000 feet. The Archean rocks occupy the core of the range. Above these is unconformably exposed in the Cottonwood canyons a conformable series of Paleozoic strata 30,000 feet thick. The nucleus of the

Archean rocks in the Cottonwood area is a mass of granite and granite gneiss. This rock at Clayton Peak possesses the physical habit of a truly eruptive granite and has been the center of local metamorphism, but the evidence points to the belief that it is of Archean age. In Cottonwood Canyon there is no sharp division between the structureless granite and the bedded gneissoid form. In the neighborhood of Clayton Peak are bodies of granite porphyry which are probably a dependent of the granite. West of the granite body of Little Cottonwood Canyon is a belt of Archean schists and quartzites having a thickness of 2,000 or 3,000 feet and dipping at a high angle to the northeast. In Little Cottonwood Canyon the quartzites are in junction with the granite, while at the mouth of Big Cottonwood Canyon, in direct contact with the granite is mica schist. Between the Archean granite and the crystalline schists there are no transitions such as to lead to the belief that the granite is a more highly metamorphic form of the schist. The contact is clearly defined, the rocks are mineralogically dissimilar, and the granite is either an intrusive mass or else an original boss over which the Archean sedimentary materials were deposited. The absence of granite dikes in the schists strengthens the belief that the granite is older. The Cambrian rocks are in such a position as to indicate that the granites and schists alike antedate them, although in some instances intrusive dikes do cut the marbleized limestone, but they are middle-age porphyries, not to be confounded with the Archean crystalline rocks.

In the next Archean mass to the north—the Farmington area—in Sawmill Canyon, there seem to be two distinct series. The later series consists of conformable beds of gneiss, quartzite, and hornblende schist, which dip west at angles of 15° to 40°, and rest unconformably upon an intensely metamorphosed material composed of quartz, orthoclase, and muscovite. In reference to the Farmington gneisses it is said: A mica schist passing into a hornblende schist, or a hornblende schist into a granite, or a gneiss rock into an argillite, along the line of their longitudinal extensions, are phenomena which fail to appear on the fortieth parallel. The small granitoid body in Sawmill Canyon is referred to the Laurentian, while the second series of metamorphic rocks, comprising the gneisses and schists, 12,000 or 14,000 feet thick, are referred to the Huronian, as are also the argillites of Salt Lake Islands.

The Paleozoic series of the Wasatch, although 30,000 feet in thickness, show in their lowest portions only a very slight tendency to become crystalline schists. The pre-Cambrian topography of the northern part of the Wasatch was that of domelike peaks with gently inclined sides. The Cottonwood canyons, however, presented an almost precipitous face of 30,000 feet to the westward. The height of the range was then, therefore, from 17,000+ to 30,000+ feet.

Passing upward from the Archean, at the base of the Paleozoic slates are Lower Cambrian slates and dark argillites and intercalated siliceous schists 800 feet thiek; above this, Cambrian quartzite, an immense series of siliceous and arkose rocks, 12,000 feet; and above this, Cambrian calcareous shales of variable thickness and containing Primordial fossils, 75 to 600 feet. This great thickness is found in the Cottonwood area, on the lower half of Big Cottonwood Canyon, and from Big Cottonwood Canyon in a northeasterly direction across the spur which divides the waters of Cottonwood Creek from Mill Creek. In other localities the Cambrian is far thinner or wholly absent. The section in Big Cottonwood Canyon comprises, from the base upward, black slates and thinly laminated argillites 800 or 900 feet in thickness; above these, 8,000 or 9,000 feet of mixed siliceous schists and argillaceous schists; and above these, 3,000 feet of true quartzite capped by 200 feet of schistose rock, quite micaceous toward the bottom, and at Twin Peak approaching a true mica schist. At the second section the series consists of four members: The bottom slates, 800 feet thick; varying siliceous and argillaceous schists, containing some mica-bearing zones, 8,000 or 9,000 feet thick; salmon-colored and white quartzites, intercalated with dark schists, 2,500 to 3,000 feet; and the capping schists, 200 feet, which are partly argillaceous and calcareous rocks and partly mica-bearing argillites. Passing up the Little Cottonwood, the successively higher members of the Cambrian rest against the granite until the latter rises into contact with the Silurian limestone, which conformably overlies the Cambrian. Although a careful search was made in these schists, no fossils were found.

Geikie,[49] in 1880, discusses the nature of the pre-Cambrian mountains of the Wasatch and the eruptive or metamorphic origin of the Cottonwood granite. That this granite is eruptive is maintained on the grounds of the enormous height of the cliff which would be required in case it was an Archean island; that if it were an old shore line, somewhere granite pebbles would be found to-day; that the granite is said by King to be a source of local metamorphism; that there are porphyries cutting the limestones, probably dependent on the granite; and that it is exceedingly improbable that there was a cliff 12 miles high which has been turned over on its back, as required by the descriptions and sections by King. All these difficulties are overcome by regarding the granite as a subsequent intrusive of post-Carboniferous age.

Walcott,[20] in 1886, describes the Big Cottonwood Canyon section of Cambrian rocks, which is found to be 12,000 feet thick. It consists of shales, quartzites, sandstones, and slates. The upper 250 feet of shale bears the *Olenellus* fauna, while other layers, although in a most excellent condition for the finding of fossils, did not reveal any. The *Olenellus* horizon is placed at the base of the Middle Cambrian and the great remaining part as Lower Cambrian.

Emmons (S. F.),[50] in 1886, discusses the possibility of the post-Cambrian eruptive character of the Cottonwood granite. This body occupies an area of about 7 by 15 miles, and a thickness of some 5 miles of sedimentary rocks abuts against its northern side, the principal members sweeping around and in part covering its eastern portion and continuing southward in an almost horizontal position. There is no especial disturbance of these beds in contact with the granite so far as observed. Neither are any masses or fragments of sedimentary rock included in the granite. Regional metamorphism has changed the sandstone to quartzite and the limestone to marble, and porphyry dikes cross the sedimentary strata, but these have no necessary connection with the granite. If the granite is an intrusive mass cutting the Carboniferous strata, it is necessary to believe that it has assimilated or eaten up more than 500 cubic miles of sedimentary rocks. If it has done this, it has left no trace of fusion in the adjoining rock, and it shows in its own structure and position no marked variation from that of a normal rock. It is further difficult to understand where the great supply of heat to do this work is to be obtained.

Walcott,[21] in 1889, places the *Olenellus* horizon at the base of the Cambrian, and regards the great series of conformable siliceous rocks, 11,000 feet thick, below this zone as pre-Cambrian or Algonkian.

Van Hise,[38] in 1889, made an examination of several canyons of the Wasatch. While the Cottonwood granite mass has a regular structure which is seen in the great cliffs, it is apparently completely massive, even in huge blocks. The apparent lamination is due to the parallel arrangement of the minerals, which have crystallized with their longer axis in the same direction. The lamination of the granite is not more marked than is the case with some of the unmistakable gabbros of the Keweenaw series. An examination of the granite in thin section shows that the feldspars have universally a well-marked and beautiful zonal structure, such as is known only in eruptive rocks. Sections of some of the black bowlder-like areas so common in the granite differ from the mass of granite only in that hornblende is more plentiful. In places the sedimentary rocks, and especially the limestones, are exceedingly metamorphosed. In one place, near the head of Little Cottonwood Canyon, at a contact with the granite, it was exceedingly difficult in the field to tell where the white granite ended and the crystalline marble began. In thin section there is no difficulty in separating the marble and the granite, so that there is no transition here. However, the granite became a true porphyry in places, a fact difficult of explanation unless it is regarded as a later intrusive.

In the Cambrian of the Little Cottonwood was found a conglomerate which carries unmistakable granite pebbles and black fragments which were thought in the field to resemble the black hornblendic areas so often observed in the granite. These, however, when examined in thin section were found to be entirely unlike those contained in the granite. The granite fragments are small and sparse and do not appear to be lithologically like the massive granite of the Cottonwood.

An examination of Weber Canyon and of the Farmington area showed that the rocks, instead of always having a western dip as described, are most intricately and minutely folded and dip both east and west, although having a general sameness of dip for considerable areas. In this canyon and in Sawmill Canyon a search for evidence of unconformity between two series of Archean rocks was unsuccessful. The schists and gneisses are cut by pegmatitic granite veins in the most irregular and intricate fashion. The main mass of the lower part of the Sawmill Canyon Archean is a series of schists. In going up the canyon, granite begins to appear, cutting the schists, and becomes more and more prominent until it is the most abundant material. It is here exceedingly coarse; and the whole appearance is that of an intrusive which has cut the schists and gneisses by numerous apophyses. It is probable that the small area referred to by King as being the older unconformable Archean was not found.

Boutwell,[51] in 1903, stated that the granite of Lone Peak and Little Cottonwood canyons, the granodiorite at the heads of Big and Little Cottonwood canyons, American Fork, and Snake Creek, and the diorite at the heads of Big Cottonwood Canyon, East Canyon, and Snake Creek, with its extension northeastward through the Park City district, in the form of dikes, are intrusive. Their intrusive origin was found to be demonstrated by the character of the contacts between the intrusives and the clastics, by the marmorization and deformation of the adjacent country rock, and by the occurrence of an unusually complete series of typical contact-metamorphic minerals. Their ages and relationships have not yet been completely established.

Emmons,[52] in 1903, agrees with Boutwell that the Little Cottonwood granite is intrusive into the Cambrian quartzite. In 1900 and 1901, on the south face of the Twin Peak ridge, a few miles below Alta, apophyses of granite were observed by Boutwell, and in 1902 by Emmons and Boutwell, to run across the bedding of the quartzite for some distance, and in one observed instance to spread out again in the beds in a considerable body. It is suggested that the Cottonwood quartzite, the Clayton Peak mass, some of the porphyritic eruptive rocks of the Oquirrh Mountains, and the extrusive andesitic lavas and tuffs of the Aqui Mountains may be related.

Boutwell,[53] in 1907, presents the detailed evidence observed by him in 1900, which proved the intrusive origin of the Little Cottonwood and Alta igneous masses. This includes apophyses, dikes, and sills extending upward from the parent igneous masses across the bedding of overlying sediments, the truncation of hundreds of feet of sediments, intense contact metamorphism, etc. This was the first positive, conclusive, concrete proof of the nature of these bodies. He concludes that the igneous rocks, considered by the Fortieth Parallel Survey to be Archean, are intrusive; that the main masses constitute a series of three or four distinct bodies, and that the Little Cottonwood granite is post-Cambrian, the Alta body is post-Carboniferous, and the Clayton Peak mass and the dikes of the Park City district are post-Permian.

PROMONTORY RIDGE, FREMONT ISLAND, AND ANTELOPE ISLAND RANGES.

Stansbury,[54] in 1853, states that granite, gneiss, mica schist, slate, and hornblende rock occur at Antelope and Fremont islands. On the west side of Fremont Island is a bold escarpment 100 feet high of talcose slate, overlain by granite and gneiss. On Promontory Point mica slate and limestone were seen.

Hague,[35] in 1877, finds the promontory of Great Salt Lake to consist of quartzites and mica-bearing schists in a conformable series, dipping to the west about 38°, and estimated to be 3,800 feet thick. In the middle of the series is a zone of calcareous sandstone, within which are several beds of limestone. In the vicinity of Promontory station the Archean schists are overlain by limestones. On Fremont and Antelope islands are outcrops of Archean rocks. The outcrop on Fremont Island consists of hornblendic and micaceous gneisses, dipping to the west, while that of Antelope Island is mostly gneisses, with some quartzites and mica slates, one of these beds becoming calcareous and approaching a limestone.

RAFT RIVER RANGE.

Hague,[35] in 1877, describes a considerable body of structureless medium-grained granite in the Raft River Range, forming the central mass.

SUMMARY OF PRESENT KNOWLEDGE.

Pre-Cambrian rocks appear in the Uinta and Wasatch mountains and in certain of the Basin ranges—Promontory Ridge, Fremont Island, Antelope Island, and Raft River Mountains.

Uinta Mountains.—Occupying a large part of the area of the east-west Uinta anticline is a great series of sedimentary rocks, estimated by Powell to be 12,500 feet thick, and called the "Uinta group." These rocks consist of shales, red sandstones, and quartzites. The whole is exceedingly ferruginous and contains seams of clay ironstone. While much time has been spent by Powell and others in the search for fossils, none have been found.

The basal rocks of the Uinta Mountains have long been regarded as comprising a small area along Red Creek Canyon, in the eastern part of the uplift. Here the red "Uinta" quartzite, with low dip, rests with apparent unconformity upon steeply dipping white quartzitic and micaceous rocks, which in hand specimen look like quartzite, but under the microscope resemble granite. Possibly they are highly metamorphosed quartzites. With them are dark interstratified hornblende schists, which resemble dikes of intrusive rocks. While actual contact is not exposed, the difference in attitude and metamorphism between the "Uinta" quartzite and underlying rocks has been regarded as evidence of unconformity. Weeks has recently suggested that the lower rocks are really to be correlated with the upper part of the "Uinta group" and that the relations are to be explained by folding and thrust faulting, he having traced certain beds of the supposed lower rocks directly into the "Uinta group."

Above the "Uinta" quartzite is the Lodore shale, regarded as Carboniferous by Powell, but later referred to the Cambrian by Weeks. Powell and White regarded the Lodore shale as unconformable upon the "Uinta" quartzite, but this also is questioned by Weeks, who regards the two formations as essentially conformable.

The "Uinta" quartzite was referred to the Carboniferous by the geologists of the Fortieth Parallel Survey, but has since been generally regarded as pre-Cambrian because of lack of fossils and inferior position, this being the recent conclusion of Weeks, Berkey, and Emmons. It is probably to be correlated with the Belt series of Montana.

Wasatch Mountains.—In the Wasatch Mountains a granite-gneiss-schist basement complex that is typical of the Archean constitutes a broad belt in the northern part of the area. The schists and gneisses are cut by pegmatitic granite veins in the most irregular manner. For instance, in the lower part of Sawmill Canyon the complex is a series of schists. In going up the canyon granite begins to appear, cutting the schists, and becomes more and more prominent, until it is the most abundant material. It is here exceedingly coarse, and the whole appearance is that of an intrusive which has cut the schists and gneisses by numerous apophyses.

Resting unconformably upon this Archean complex is a great series of sedimentary rocks. These consist of mica slates, mica schists, argillite, and intercalated siliceous schists, 800 feet thick; above these is a great quartzite formation 12,000 feet in thickness; conformably above the quartzite are 250 feet of shales, which according to Walcott contain *Olenellus* fauna. Walcott says that this lower series, although in a most excellent condition for affording fossils, did not reveal any. The pre-*Olenellus* rocks are rather gently folded, although the dips are sometimes steep. The metamorphism of the rocks is largely by consolidation and cementation, although the quartzites everywhere show the effects of orogenic movements and in places approach quartz schists. The series is here correlated with the " Uinta " quartzite and the Belt series, and is therefore assigned to the Algonkian.

To the south, in the Little Cottonwood district, is a great mass of white, laminated granite. King and Emmons believed the evidence, on the whole, to favor the pre-Algonkian origin of this granite. Geikie, from a few general observations, later believed it to be intrusive. Van Hise inclined toward Geikie's view. The observations of Boutwell in 1900 finally proved the intrusive character of this granite. These views were accepted by Emmons in 1903.

Promontory Ridge, Fremont Island, and Antelope Island.—In the range composed of Promontory Ridge and Fremont and Antelope islands the Archean rocks occur in typical development. Resting on these, according to Hague, is a conformable series of quartzites and mica schists containing a zone of calcareous sandstones and several beds of limestone, the whole estimated to be 3,800 feet in thickness. No fossils are found in these rocks, and they are presumably the equivalent of the quartzites of the Wasatch Mountains, and therefore probably Algonkian.

SECTION 5. NEVADA.

SUMMARY OF LITERATURE.

Schiel,[55] in 1855, states that in the Humboldt and other island mountains of the desert west of Salt Lake are granites, syenites, quartzose rocks, and clay slates.

Gilbert,[16] in 1875, states that the ridges of the Basin Range system are in part composed of granitic and cognate rocks. The granite occupies various positions. Often it is the nucleus of the range against which inclined strata rest. Elsewhere it appears in dikes, traversing either the sedimentary rocks or other granites. In a few instances it was observed to overlie the sedimentary rocks, while in a number of localities the evidence of its eruptive character is unequivocal; in others it is plainly metamorphic, and in by far the majority of cases it appears to have assumed its relation to the undoubted sedimentary rocks before the upheaval of the combination. In the Granite mining district the section shows a white crystalline marble overlain by granite, which appears to extend from the summit of the range to the opposite base. The axis of the Snake River Range consists of quartzite and limestone, with a limited amount of crystalline schists and granite. Metamorphic sedimentary rocks of undetermined age were seen at a number of points and have been regarded provisionally in mapping as Archean, with which have been grouped the granitoid rocks.

MARVINE,[17] in 1875, states that crystalline rocks are found on the Salt Lake road in the Virgin Mountains.

HOWELL,[48] in 1875, states that Granite Rock is an island of granite in the desert, which shows traces of bedding, with a high dip to the west. The nucleus of Snake Range is granite, exposed at many places, and overlain by quartzite, shale, and limestone.

EMMONS (S. F.) and HAGUE,[35] in 1877, describe the mountain ranges of the Nevada plateau and the Nevada basin.

Granites constitute the entire cores, or a large part of the cores, in the following ranges: Ibenpah, Wachoe, Antelope, Schell Creek, Egan, Franklin Buttes, Ombe, Gosiute, Peoquob, East Humboldt, White Pine or Pogonip, Wahweah, Cortez, Seetoya, Shoshone, Toyabe, Augusta, Fish Creek, Havallah, Pahute, West Humboldt, Montezuma, Pahtson, Granite, Pahsupp, Sahwave, Truckee, and Lake.

In the hills between Antelope and Schell Creek mountains, in the Goose Creek Hills, and in Franklin Buttes, granite porphyry is also found. In the Franklin Buttes there is a gradation from syenitic granite, through granite porphyry, into genuine felsite porphyry. The hills between the Antelope and Schell Creek ranges contain cores of granite, east of which are interstratified beds of dolomite, marble, and dikes of granitic porphyry. These are considered to represent the development of an Archean body.

The granite of the Wachoe Range is different in lithological character from the Raft, Ombe, Gosiute, and Peoquob ranges, and is therefore regarded as eruptive. No decisive evidence shows its age, but it is regarded, because of the nature of its occurrence, structure, and mineralogical habit, as probably Jurassic. The granite of the Fish Creek Mountains is structureless and would seem to be an intrusive body. The entire mass of the Pahsupp Range consists of granites which resemble the later granite of the Pahtson Range.

The Cluro Hills of the Cortez Range are composed of syenite granite, which is the only true syenite found in the region.

The East Humboldt, Shoshone, West Humboldt, Montezuma, Pahtson, Truckee, Lake, and Pea Vine mountains contain, besides the granitic rocks, various crystalline slates and schists which are regarded as Archean. On Spruce Mountain of the Peoquob Range are mica schists and mica slates which probably belong to the older series, but the relations are obscure. They are distinctly bedded, finely laminated, and similar to the crystalline schist series of the Humboldt Range. The East Humboldt Range, the main range of central Nevada, is a mass of Archean rocks, which acts as the axis of an anticlinal fold and upon which rest unconformably the Devonian and Carboniferous strata. The southern part of the range is composed of granite in two large areas, which at White Cloud Peak possesses the characteristics of an eruptive granite, there being no distinct lines of bedding, although divisional planes are noticeable. The northern granite mass is unconformably overlain by a series of quartzites, hornblende schists, and gneisses which contain beds of dolomitic limestone from 1 to 6 feet in thickness, separated by micaceous quartzites and mica schists. This series, estimated in the northern part of the range to be from 5,500 to 6,000 feet in thickness, is best seen on Clover Canyon and Boulder Creek. There is every gradation between the coarse gneissoid phases and the fine-grained mica schists. The granite of the Humboldt is similar to the Laurentian of the Appalachian, while the unconformably overlying series closely resembles the eastern Huronian. In the Southern Shoshone Range an original Archean island is wrapped around by fine-grained micaceous slate. The Archean granite of Ravenswood Peak has remarkably regular bedding planes, apparently conformable to those of the overlying slates, which give it the appearance of being a stratified granite, although it at the same time traverses the slates in dikes. The Ravenswood Peak granite to the east is essentially different from the Archean granite and is evidently of later origin. In the West Humboldt Range the granite shows structural planes. Along its northern and western edge it is overlain by a series of metamorphic schists and gneisses, which are in turn overlain by fine, white, knotted schists. The strike of these beds is N. 38° E., and they stand nearly vertical. The contact of the granite and schist shows in a horizontal plane irregular angular intrusions of the former into the latter, masses of schists lying in the granite and extending as promontories from the main mass for 400 or 500 feet. The line of demarcation between the two bodies is easily observed, and there seems to be no tendency for the schists to pass by gradation into the granite. Dikes penetrate both the granite and the schists. The range is regarded as an anticlinal fold. In the Montezuma Range are slates and schists which rest unconformably upon the granite. The Pahtson Mountains consist almost entirely of granite and crystalline schists, which are cut by numerous dikes, the whole being regarded as Archean, because the dikes do not cut later eruptive granites, which are found in considerable quantity, and differ markedly from those which are regarded as Archean. In the Truckee Range are found quartzitic schists and hornblendic rocks with both older and later types of granite. The metamorphic schists cut by intrusive granites referred to the Archean occupy but a small area, the later granites making up the greater part of the range. In the Lake Range are granite and

Archean gneissic rocks, which are quite unlike any other observed rocks in western Nevada. The Pea Vine Mountains consist of quartzites and fine-grained feldspathic rocks, which are referred to the Archean, but their relation to the other crystalline rock masses has not been made out.

In Schell Creek, Egan, Pogonip or White Pine, and Piñon ranges the granite is overlain by Cambrian strata. In the Schell Creek Mountains are limestones bearing Primordial fossils overlying heavy bodies of Cambrian quartzite. In the Egan Range, overlying the granite, is a series several thousand feet thick of quartzites and quartzitic schists with a 50-foot bed of roofing slate. The main mass of quartzite is thoroughly vitrified, showing little trace of granular structure. A portion of the quartzite shows evidence of having been subjected to great pressure, and the slate at times gets to be micaceous, and even becomes a normal mica schist. This series doubtless represents the Cambrian, but the direct contact of the overlying limestones was not observed. Overlying the granite of the Pogonip Mountains, apparently unconformable with the granite, are outcrops of mica slate and black arenaceous and argillaceous slates and shales, in turn overlain by an undetermined thickness of compact vitreous quartzite. Above this quartzite (regarded as Cambrian because resembling the Cambrian quartzites of the other Nevada localities) occurs the Pogonip fossiliferous limestone, the higher beds of which are referred to the Quebec group. In the Piñon Range, below the heavy Silurian limestone, occurs a heavy bed of red and brown quartzite underlain by mica schists and quartzitic schists 5,000 feet in thickness, which from their position inferior to the Silurian and their similarity to the Wasatch Cambrian are referred to the Cambrian age.

In the East Humboldt Range, overlying the granite is quartzite, which is referred to the Ogden, but without any overlying rock. In the Wahweah Range surrounding the granite occurs a heavy bed of quartzite, which is referred to the Ogden Devonian, although but little examined.

In the Ombe, Gosiute, Peoquob, Little Cedar, Toyano, Fountain Head, Cortez River, Northern Cortez, and Battle ranges the rock overlying the granite is a nonfossiliferous quartzite referred to the Weber. These quartzites are generally of a bluish-gray color, contain flint and chert fragments, often angular, and jasper pebbles, sometimes have thin seams of carbonaceous material, are often ferruginous, and not infrequently conglomeratic. At these ranges the Weber is overlain by heavy bodies of limestone referred to the Upper Coal Measures, generally carrying fossils to the contact with the quartzite. At most of these ranges the quartzite is several thousand feet thick, sometimes as much as 6,000 or 7,000. At Pilot Peak of the Ombe Range, interstratified with the quartzites are mica schists, and the series resembles the Cambrian of Bonneville Peak, Aqui Mountains. In the Seetoya and Shoshone ranges the quartzites referred to the Weber are between heavy beds of limestones, and in Two Cubits it conformably overlies an enormous development of Wasatch limestone.

The stratified rocks overlying the Havallah, Pahute, West Humboldt, and Truckee granites are referred to the Triassic; those overlying the granites of the Pahsupp Range are referred to the Jurassic; while the gray slates resting unconformably above the Sahwave are referred to the Miocene. These references are mostly made on lithological grounds, because no Paleozoic strata have been recognized west of the Battle Mountains, although in certain cases paleontological evidence is found.

It is remarked that throughout Nevada are large bodies of quartzites without any clue to their stratigraphical relations with an underlying or overlying limestone, the adjacent rocks being either granites or Tertiary volcanic outflows. It is then exceedingly difficult, if not impossible, definitely to determine their true geological horizons. In many cases lithological and structural resemblances furnish a strong aid, and, when followed up, not infrequently throw the evidence in favor of one or the other of the great zones of quartzites; but in many cases such resemblances are meager, and the references are made on theoretical grounds, being on slight evidence, or even personal impressions received in the field.

King,[36] in 1878, describes many of the Nevada ranges.

In the Gosiute Range the Archean rocks are granite, granite porphyries, and crystalline dolomites, all of which are interlaminated and are chemically allied to those of the Humboldt Range. That the granite porphyries are interstratified with the marbles confirms the probability of their being metamorphic.

The Archean of the Humboldt Range, with the exception of a small body of granite, is composed of a conformable series of gneisses, gneissoid schists which are sometimes hornblendic, dolomitic limestones, and quartzites, all of which dip to the west. It is evident by the entire absence of easterly dipping Archean and Paleozoic rocks that a fault similar to that at the Wasatch has cut down the core of the range from north to south, and that the eastern half is depressed below the level of the Quaternary plain. The White Cloud Peak granite bears a singular resemblance to some of the Huronian granitoid rocks, also conceived to be metamorphic. The granite appears to underlie conformably the series of schists. The gneisses of Clover Peak can not be distinguished in hand specimen from a granite, except that there is an indistinct parallelism of its dark constituents. Between this stage and the truly schistose gneisses there is every possible transition. The limestone series is not more than 50 or 60 feet thick, in beds from half an inch to 6 feet. Intercalated with the limestones are gneiss and porphyries very like those in the Gosiute Range. The upper beds pass through a transition into the pure quartzites. The Humboldt Archean schists have a family likeness with those of the Farmington region of the Wasatch and those of the Medicine Bow.

In the Cortez Range a central body of granite is invaded by syenites, and is overlain on the west by a quartzite, which is, for the sake of convenience, referred to the Weber.

In the Shoshone Range the stratified series dip away from the central mass, which has rather the appearance of an intrusive core. From their likeness to other known Archean rocks, and for want of reasons to the contrary, these schists, together with the granite, are referred to the Archean. Regular parallel divisional planes are seen in the granite, so as to give it an appearance of stratification, but as it penetrates the schists in the form of a dike, there is no doubt of its eruptive origin.

In the Havallah Range, associated with the older granites are intrusive granite bodies, but such occurrences are exceptional along the area of the fortieth parallel.

In the West Humboldt Range a variety of crystalline schists are found unconformably upon the granite, no tendency toward a passage between the two rocks being shown, and dikes of granitic material invade the schists. In the schists are roundish areas of quartz, which might be explained on the supposition that they are the pebbles of conglomerates, but they are more probably an aggregation formed during metamorphism.

In the Montezuma Range the granite of Trinity Peak is undoubtedly of eruptive origin, as may be determined from its general habitus and from its penetrating the Archean schists in well-defined dikes.

In the Pahtson Range the Archean nucleus consists of crystalline schists, a limited amount of granite, and a subsequent granite which has cut through the older granites and schists. These are all cut by dikes of later age, but supposed to be Archean.

The Truckee Range is composed of schists and granite representing two periods of formation.

The Pea Vine Mountains consist of a series of conformable, highly altered beds, striking N. 50° to 65° E., made up for the most part of fine-grained quartzite strata, riven in every direction with minute fissures, which are filled with ferruginous material.

It is remarked that in the absence of any granitic dikes penetrating the stratified series, or of peculiar local metamorphism, or general evidence of intrusion, the bodies are usually referred to the Archean. Only in cases where the granite is actually seen to penetrate the openings in the strata is it safe to refer it to a later age than the sedimentary series.

In the analytical map the rocks are divided into two classes, the intention being to discriminate those formations which are sedimentary from the class of eruptive rocks; but this line can not be drawn with precision, because the series of gneisses pass into the massive layers and because limited bodies of granite which are massive might if more largely exposed pass into crystalline schists or other Archean sedimentary rocks.

It is not easy to analyze those subtle appearances which lead the observer to incline to one or the other of the two possible modes of origin of a granite outcrop. Parallelism of bedding, and even parallelism of the arrangement of minerals, are consistent with the theory of an eruptive origin. Certain masses of gneissoid granite appearing in the great eruptive granite body of the Sierra Nevada show quite as much parallelism of bedding and internal arrangement of minerals as the Rocky Mountain granites to which we have assigned a metamorphic origin; yet the Sierra field, as a whole, is clearly eruptive. But at the same time, in the intimate arrangement of the mineral particles and in the mode of contact between the various mineral ingredients, there is a certain broad uniformity in all the eruptive granites, which produces a characteristic impression upon the eye. On the contrary, the granites which we conceive to have been of metamorphic origin, no matter how simple the mineralogical composition, have always a peculiar variability of arrangement; and even in the absence of any pronounced parallelism they show the effect of interior compression and irregular mechanical influences. In the eruptive granites there seems to have been a steady expansive force, doubtless due to the heat and elastic fluids, which gave to all the particles a certain independent polarity, while in the metamorphic granites they seem to have been crowded into constantly conflicting positions. As the result of this, the crystalline particles of the metamorphic granites are much less apt to have completed their crystallization, or, if it was completed, they have been crushed and torn asunder and their particles scattered, while in the case of the eruptive granites crystallization seems to have been more perfected. The result of this is to give to the eruptive granites something of the uniformity of texture of a volcanic rock, while all the metamorphic granitoid rocks, when once the gneissoid parallelism of minerals is broken up, have a crushed, irregular, and confused mode of arrangement.

The metamorphic rocks of the Humboldt Mountains, Franklin Buttes, and the Kinsley district are provisionally correlated with the Huronian of Canada.

The foregoing ranges are referred to the Archean simply on petrological evidence. This mode of correlation is dangerous, but a general study of the whole region has strengthened the belief that in the Paleozoic series as a whole there are none of those results of extreme metamorphism which in the Appalachian system are described by some geologists as closely approximating to Archean forms.

Besides mentioning localities given by Hague in which Cambrian is found, it is said that an excellent exposure of Cambrian schists and quartzites is found underlying the Pogonip limestone in the range of hills including the Eureka mining district and connecting the Diamond and Piñon ranges.

HAGUE,[56] in 1883, describes the Eureka district as a mountain block standing between the Piñon and Diamond ranges. At the base of the series is the Prospect Mountain quartzite, 1,500 feet thick, over which is a shale 100 feet in thickness bearing the *Olenellus* fauna. One small area of granite is found. The Prospect Mountain quartzite lies in contact with it and dips away from it in irregular broken masses.

WALCOTT,[20] in 1886, describes the Eureka series of Nevada as middle Cambrian and finds at the top of the Prospect Mountain quartzite the *Olenellus* fauna. In the adjacent Highland Range a more abundant fauna is found in the lower 1,500 feet of quartzite.

WALCOTT,[21] in 1889, places the lower quartzite of the Eureka and Highland sections as basal Cambrian.

SPURR,[57] in 1903, describes and maps the geology of Nevada south of the fortieth parallel and adjacent portions of California. He mentions the occurrence of pre-Cambrian rocks in the Colorado Canyon and in the Colorado, Egan, Eldorado, Humboldt, Kern, Sierra Nevada, Snake, and Virgin ranges.

BALL,[58] in 1907, reports on a geologic reconnaissance in southwestern Nevada and eastern California. The presence of pre-Cambrian rocks was not definitely determined. The Prospect Mountain quartzite (lower Cambrian) of the Specter Range contains pebbles of quartzite, jasperoid, and vein or pegmatitic quartz derived from pre-Cambrian formations. The mica schist of the Bullfrog Hills is pre-Ordovician, and although considered of Cambrian age, it may be pre-Cambrian. The schist at Trappmans Camp and the series in the south end of Amargosa and Panamint ranges are also probably Cambrian, although possibly pre-Cambrian.

WEEKS,[59] in 1907, discusses the pre-Cambrian geology of the Snake Range of eastern Nevada. It is in general an east-west anticline, the structure being nearly at right angles to its trend. The southern side of the fold is quite symmetrical, but the northern is broken by many faults having the same general trend as the anticline.

Wheeler Peak, having an elevation of 12,000 feet, is formed in part of pre-Cambrian quartzite standing nearly perpendicular. The dip is to the south-southwest, gradually decreasing to 15°, and Lower, Middle, and Upper Cambrian, Ordovician, and Lower Carboniferous strata are exposed before the range dies out to the south. On the northern and western slopes of Wheeler Peak there is exposed a small area of granite and schistose rocks which may represent the basement complex. The granite is intruded by several coarse-grained dikes of quartz porphyry. It varies from fine to coarse grain and on the western slope in the vicinity of the hübnerite mine has a rudely bedded structure parallel to the dip of the sedimentary beds.

On the northern slope of the peak there is exposed from 100 to 200 feet of conglomerate composed of subangular masses of granite and quartz porphyry. At the base the material varies from the size of an egg up to 6 or 8 inches in diameter. The material rapidly becomes smaller and more rounded and grades into quartzite. This is succeeded by soft, argillaceous, and siliceous schists, well exposed along the Placer Company's ditch. These are followed by other quartzites, which underlie shales in which was found *Olenellus*.

The determination of the Archean age of these granites and schists rests on the occurrence of what certainly appears to be a basal conglomerate composed of granitic material. This is the only occurrence of the kind in the Great Basin region known to Weeks. There are many other localities in which sedimentary rocks varying from Cambrian to Carboniferous are in contact with granitic masses. In the vicinity of Wheeler Peak, however, no rocks except the pre-Cambrian quartzite was seen in contact with this granite.

SUMMARY OF PRESENT KNOWLEDGE.

In the basin ranges of the northern part of Nevada the geologists of the Fortieth Parallel Survey mapped and described a number of granitic areas as pre-Cambrian. It is probable that some at least of these supposed pre-Cambrian granites are later than the pre-Cambrian and are intrusive into the sediments. In the Star Peak Range, for example,[a] granite which the Fortieth Parallel geologists considered Archean has been lately shown to be post-Triassic and probably post-Jurassic. The state of knowledge in regard to the whole area of the Fortieth Parallel maps is therefore not such as to allow one to accept their conclusions without further examination. In the areas to the south of that mapped by the Fortieth Parallel Survey Spurr maps a considerable number of granitic areas, but concludes that all of them are later than the pre-Cambrian, with

[a] Louderback, G. D., Basin range structure of the Humboldt region: Bull. Geol. Soc. America, vol. 15, 1904, p. 318.

the exception of those in the Snake Range and Colorado River areas. In the Snake Range intrusive phenomena are to be observed, but Spurr believes these to be associated with later rocks, similar in composition to an earlier granitic mass, which is probably pre-Cambrian.

Sedimentary rocks, apparently lacking fossils and underlying Cambrian rocks, are mapped by the geologists of the Fortieth Parallel Survey in the Schell Creek, Egan, Pogonip, Snake River, and Piñon ranges. These geologists call them Cambrian, and call attention to their similarity to the quartzites of the Wasatch Mountains. No systematic search for fossils has been made in these beds. Although the *Olenellus* fauna has been found in many places in the overlying Cambrian beds, Walcott is not sure that he has found the bottom of this fauna. Hence the underlying beds may be Algonkian or Cambrian. They are here provisionally assigned to the Algonkian because of their apparent lack of fossils and their occurrence beneath the known Cambrian. In Idaho and Montana a sedimentary series in a similar position has been found to be pre-Cambrian.

In the Schell Creek Range the probable Algonkian is represented by heavy bodies of quartzite. In the Egan Range the probable Algonkian is represented by a series of thoroughly vitrified quartzites, several thousand feet thick, containing quartzitic and micaceous schists. In the Pogonip Range it is represented by micaceous, arenaceous, and argillaceous slates and shales and by vitreous quartzite, the series being of undetermined thickness. In the Piñon Range it is represented by quartzites underlain by mica schists and quartzitic schists, having a total thickness of 5,000 feet.

In the Snake Range of eastern Nevada are quartzites and argillaceous and siliceous schists underlying shales in which is found the *Olenellus* fauna. At the base of the quartzite is a conglomerate 100 to 200 feet thick, carrying fragments of granite and quartz porphyry from underlying granitic rocks. Weeks cites the Snake Range as the only one known in the Great Basin in which the granitic rocks have been found to be separated from pre-*Olenellus* sediments by a marked unconformity.

The Colorado River Algonkian is described under Arizona, section 3 (pp. 777–779).

SECTION 6. COLORADO.

SUMMARY OF LITERATURE.

FRONT RANGE NORTH AND EAST OF THE ARKANSAS.[a]

LONG,[60] in 1823, describes granite as succeeding pudding stone or conglomerate on Defile Creek. The granite is coarse grained and rapidly disintegrates.

[a] For southward continuation of Front Range, see section 2, this chapter, pp. 768–770.

HAYDEN,[61] in 1869, states that all the mountains east of the South Park have a gneissic and granitic nucleus. Each of the great ranges of the park are anticlinal axes with massive granite cores and gneissic granites inclining from each side in the form of ridges. The trend of the ranges is in most cases northwest-southeast, or nearly so. The Azoic rocks have two planes of cleavage, one of them with a strike northeast-southwest, and the other at right angles. Besides these cleavage planes there are in most cases distinct lines of bedding. At Golden the sandstones lie close to the metamorphic rocks, inclining 30° to 54°.

MARVINE,[62] in 1874, describes fully the metamorphic crystalline rocks of the Front Range. The rocks of this great area are mostly composed of schists, gneisses, and granites. Disregarding unimportant occurrences of undoubted ancient eruptives, as well as some minor granite areas of uncertain nature, the series as a whole must be regarded as a system of ancient sedimentary rocks which have undergone the most profound metamorphism, the result of which over large areas has reached the last term—structureless granite. Considering its extent and antiquity, the formation as a whole is remarkably simple and uniform, running from quartzite through siliceous and mica schists to very simple varieties of gneisses and granites in which the mica is wholly subordinate. The least metamorphosed rocks observed were excessively hard and compact quartzites found in the lower canyons of Coal and Ralston creeks. They here pass into a series of highly siliceous schists, in places ferruginous, in which may possibly be found workable deposits of iron ore. These are associated with fine siliceous mica schists, above which are very irregular schists, intercalated together. Gneissic and granitic strata are frequent, while below is a great granite mass which, though there are but few remnants of bedding left, is apparently conformable with the series above. A similar succession was observed near the Little Thompson, quartzites being found at the top and granites at the base. On South Saint Vrains and at the mouth of South Boulder Canyon is found quartzite resting upon zoned but structureless granite. The Triassic shales rest unconformably upon the mica schists on Little Thompson. The dominant rocks are granitic and gneissic, although schists are found over large areas, and of these the tendency is toward a binary granite to which the name aplite might apply.

That the characters noted above are evidence of a structure that once existed throughout the whole mass; that the inclosed schistose patches and areas are neither remnants of foreign schists inclosed in an eruptive granite mass nor accidental lamination developed by crystallization or motion in a plastic rock, is abundantly proved by the fact that, whenever over a continuous area a great many of the strikes and dips of such remnants are carefully noted and platted on the map, they are invariably consistent among themselves in indicating a definite structure of the whole, and accord with the structure that may be indicated by neighboring schists and other masses of undoubted bedded rocks.

As in the derived sedimentaries is found débris from the crystalline rocks, it is concluded that the folding which affected the metamorphism is older than that which has upturned the sedimentary strata. It is not supposed that sufficient heat was necessary to cause dry fusion, but aqueo-igneous fusion.

While it is exceedingly difficult to obtain structural results, a map of the eastern slope of the Front Range is presented. The portion in which the structure is most clearly made out is that south of South Clear Creek and having Mount Evans as its culminating point. The granite of Mount Evans occupies as low a geological position as any rocks in the range. No special facts bearing on the equivalency of the metamorphic series to any of the divisions of the Archean of the East were observed.

Peale,[63] in 1874, describes several sections in the Front Range at Pleasant Park, Glen Eyrie, Bergen Park, and Trout Creek, in all of which the granite underlies the fossiliferous series. On the South Platte, at the change from the sandstone to the granite the former contains fragments of unchanged granite. In other places the sandstone appears to pass, by gradations, into the granite. Pikes Peak is composed of fine-grained reddish granite, the origin of which, whether eruptive or metamorphic, is a question. On the road from Colorado Springs to South Park is a granitic ridge which seems to be thrown up through the coarse beds which lie about it. In the range of the South Park several sections of the fossiliferous series are described which rest upon granite or gneiss. At Georgia Pass eruptive granite forms the peak, while black micaceous gneiss is at the base of the series, there lying between the two slates and quartzites. At several of the sections given the basal layer of the series is a quartzite.

Endlich,[64] in 1874, describes granite as forming the heaviest mass of rock north and east of the Arkansas and south of a line running east and west 6 miles south of Pikes Peak. On Cottonwood Creek the rock resembles a gneiss. Resting immediately upon the granite are the Silurian, characterized by but a few fossils, and the well-known quartzitic formations. The granite of this area is the oldest found in the region.

Stevenson,[65] in 1875, states that metamorphic rocks occur in the Front Range. On the North Fork of the South Platte the schists are much contorted. The schists near Bailey's ranch contain rudely oval nodules of quartz and feldspathic granite, which in several localities are observed in layers. In many instances the large masses of gneissoid granite string out like veins on all sides from the center, and these veinlike projections break up into these nodules, and thus finally disappear. It is sufficiently evident, then, that these are not metamorphosed pebbles, but concretions, the result of segregation, which mark the formation of the separate layers of quartz, feldspar, and mica in gneiss and of the great masses of coarse granite which occur so frequently in the gneisses and schists. Gneissoid granite is exceedingly common. It often occurs in the gneiss as great included masses of irregular shape or in elongate, vein form, spreading from a center and throwing out seams which become exceedingly thin before they disappear. In each instance the deposit seems to bear no relation to the bedding of the including rock. For the most part, however, it is found entirely displacing the gneiss and forming the prevailing rock for miles, although in every such instance it occasionally changes into gneiss for short distances. Not infrequently seams of granite are found along the planes of cleavage. This granite, which may be termed segregated granite to distinguish it from the granite which many regard as eruptive, is coarsely crystalline, with the feldspar in great quantity, while the proportion of mica is very small. The feldspar varies in color from white to red, and the rock as a whole yields readily under the influence of the weather. The gneissoid granite of Taylor River exhibits granite of both the eruptive and the metamorphic varieties, one passing into the other with no line of separation. There is, then, no room to doubt that they are of common origin and that the whole is metamorphic.

The gneiss of Tenmile Creek is compact and might be mistaken for a quartzite. Below the junction is an immense segregation of granite, thoroughly veinlike, interlacing and running across the bedding in every conceivable way, but not persistent, as each of the veins tapers off until it disappears. In the canyon of the Arkansas, above the junction with Tennessee Creek, is a gneiss which has very close affinities to the granites usually called eruptives. It passes gradually into a micaceous schist. On Trout Creek is syenite, succeeded by granite, which gradually assumes a gneissoid structure and contains fragments of gneiss from 6 to 20 inches in diameter that are fragmental in shape. Their presence is difficult to account for. If the granite is eruptive, these might be included fragments, but there is no reason to assign any such origin to it, for its gradual passage into the gneiss is easily traced. On Currant Creek, at the west side of South Park, near Mount Lincoln, at Idaho Springs, and on the east side of South Park massive granite or syenite is seen grading into gneiss and mica schist. At Chicago Creek coarsely crystalline granite is sharply separated from the adjacent gneiss, the junction being as sharp as between a trap dike and the adjoining rock. Some of the porphyritic rocks, granites, and syenites are placed among the eruptives. This is done in deference to commonly received opinion; but as there is no locality in which these rocks do not pass imperceptibly into gneiss, the conclusion is reached that the preponderance of evidence is in favor of their metamorphic origin.

In speaking of Colorado metamorphic rocks in general, Stevenson says that the prevailing rock is a micaceous schist passing into gneiss and containing much granite, which in some localities entirely replaces the others. Not infrequently the mica schist is displaced gradually by hornblende schist, which becomes a hornblende gneiss, containing masses or strings of syenite, as the other form contains ordinary granite. Slates are almost wanting, and thick strata of quartzite belonging to this series were observed at only two or three localities. Serpentine and limestone seem to be absent altogether. It is impossible in the present state of our knowledge to come to any definite conclusion respecting the relations of these rocks. Hayden, in one of his reports, has referred them with doubt to the Laurentian. To determine this matter careful investigation at the north is still needed.

KING,[36] in 1878, states that in the Colorado Range are two series which are probably unconformable. The upper group is distinctly bedded, has a variable amount of mica, and is correlated with the upper horizons of the Medicine Bow and the higher members of the Park Range, Red Creek in the Uinta, the Wasatch, and Salt Lake islands, and the exposures in the Humboldt Mountains, Franklin Buttes, and Kinsley district. In the Clear Creek region the series is not less than 25,000 feet thick.

EMMONS (S. F.),[66] in 1890, states that Cross has discovered in the hills east of the Arkansas River, at Salida, a thickness of about 10,000 feet of slates and schists entirely distinct from the Archean and probably unconformable with it. These are referred to the Algonkian.

LAKES,[67] in 1890, made observations upon the district of South Boulder, Coal, and Ralston creeks. In the South Boulder and Coal creeks area were found between the Trias and the heavily bedded gneisses a series of quartzites, schists, and conglomerates, the clastic character of which is unmistakable. The series has been subjected to intense dynamic action, so that the pebbles of the conglomerate are elongated, and if it were not for the bands of this material it would be difficult to show that the series was an original clastic one, as the finer grained rocks are completely crystalline quartz schists and mica schists. The dip of the series is at a high angle away from the main mass of the mountains. Its higher members are quartzite and pass down into mica schists and quartz schists, which are interstratified with beds of conglomerate. In passing downward the mica schists become interlaminated with gneiss, which becomes more and more abundant, and on Coal Creek, cutting the schists, are also pegmatitic granite veins. Nowhere between the clastic and the gneissoid series was any discordance discovered, there appearing to be between them a gradation, although a somewhat rapid one. The clastic series at South Boulder Creek is at least 1,000 feet thick. The lower gneissoid series at times is in part quite regularly laminated, at other times becomes a heavily bedded granite gneiss, but for several miles toward the core of the mountains, as far as investigated, does not become structureless granite.

On Coal Creek, at one place within the clastic series, is a wedge of granite of considerable thickness, and this does not grade into the clastic rocks as does the main granitoid gneiss area. The relations of the Trias both to the granite gneiss and to the clastic series are such as to show that it is clearly a later formation, separated from them by a very great unconformity.

At Ralston Creek the heavily bedded gneisses were found to vary into hornblende gneiss interlaminated with granite veins, and these into rather fine-grained schistose rock, but there was discovered here no clear evidence of a clastic series, although the more schistose phases immediately under the Trias may represent the more altered clastic schists of Coal and South Boulder creeks.

Cross,[68] in 1894, describes and maps the geology of the Pikes Peak quadrangle. The oldest rocks here found are Algonkian quartzites and allied rocks, which occur as fragments included in the granite. These vary in size from that shown in Wilson Park to minor fragments. The Wilson Park mass is nearly 4,000 feet in thickness, stands on end, and is exposed along the strike for about 5 miles. Other important masses of quartzite are in Cooper Mountain and Blue Mountain. These masses are cut by minute dikes and are entirely surrounded by granite. Smaller fragments are very numerous. Associated with the quartzites are certain gneisses and schists which almost grade into the quartzites, and probably represent metamorphosed Algonkian strata. Schists also occur, especially in the Cripple Creek district, and these seem to represent earthy metamorphosed Algonkian rocks, and also the true Archean gneisses upon which the Algonkian beds were deposited. Later granites and gneissoid granites occupy much the larger part of the Pikes Peak quadrangle. The more important granites are the coarse-grained Pikes Peak type and a fine-grained granite. The gneissoid granites are but foliated phases of the granites, and between the two there are gradations. All the granites are cut by coarse granitic dikes and veins. The Silurian rocks rest unconformably upon, and derived fragments from, all the previous formations. The base of the known Paleozoic section in Colorado is an Upper Cambrian quartzite which in the Colorado

Range rests upon the granite and gneiss containing these quartzite inclusions. In the light of present knowledge concerning pre-Cambrian sediments in the West it is deemed better to refer the included sedimentary rocks to the Algonkian. No Cambrian formation is represented on the map, although it is probable that a small thickness of quartzite and of cherty limestone below the Manitou Silurian limestone belongs to that period.

Cross,[69] in 1895, describes the geology of the Cripple Creek district of Colorado. The account of the general geology is substantially the same as that previously given by Cross for the Pikes Peak quadrangle, of which the Cripple Creek district is a part. Granites and gneisses occupy a large area in the district. Included in these granites and gneisses are large and small fragments of quartzite, quartz fibrolite schist, quartz mica schist, and other similar rocks. It is believed that the quartzite fragments belong to a great series of pre-Cambrian (Algonkian) sediments. Hence the granites including such fragments are not Archean; but they are older than the only Cambrian rocks as yet identified in Colorado, and they are therefore mapped as Algonkian. The schists are probably also sedimentary, but it is quite possible that some, if not all, have been produced from Archean gneisses forming the foundation upon which the Algonkian sediments were laid down.

Emmons, Cross, and Eldridge,[70] in 1896, describe and map the geology of the Denver Basin in Colorado. Pre-Cambrian rocks form the mass of the Colorado or Front Range along the western border of the Denver Basin, later formations resting against the flanks of the mountains. In the lower canyons of South Boulder and Coal creeks are beds of highly altered quartzite and conglomerate, associated with schists, aggregating a thickness of 1,000 feet, which occupy a position between Triassic sandstones and the gneisses of the interior of the range. These are undoubtedly sedimentary and are probably of Algonkian age. In passing from these sedimentaries westward toward the center of the range there appear successively gneisses, granite gneisses, and massive granite. As the areas occupied by the granites and sedimentaries have not been definitely delimited, and as the sedimentaries occupy but a small proportion of the pre-Cambrian area, the sedimentaries are not mapped as Algonkian, but, with the granites, are mapped as pre-Cambrian.

Crosby,[71] in 1899, describes the Archean-Cambrian contact near Manitou, Colo. A sandstone of Cambrian age rests upon an Archean granite complex. The granite floor has very small erosion inequalities. These inequalities are hummocks, not hollows; erosion remnants, and not channels; clearly marking the end and not the beginning of a process of base-leveling.

It is believed that such an even contact plane between the Cambrian and pre-Cambrian series is widespread and characteristic in North America. It appears to be the case in the valley of the Eagle River and in the canyon of the Grand River above Glenwood, Colo.; in the Black Hills of South Dakota, examined by the writer; in the Grand Canyon of the Colorado, described by Walcott; and in Wisconsin, described by Irving.

In the Manitou, Eagle River, and Black Hills areas, throughout the Rocky Mountains, and eastward to Champlain Valley and beyond, the Cambrian has a nonarkose character; it has been thoroughly sorted and washed by water, a fact which indicates that the incursion of the sea was an extremely slow one. It is believed that the plane surface of the Archean has resulted from the incursion of the sea due to the subsidence of the land, and not from the action of subaerial agents, for in the latter case only an approximate plane could have resulted because of differential erosion.

Mathews,[72] in 1900, gives a detailed petrographic description of the granites of the Pikes Peak quadrangle, in Colorado. They are referred to the late Algonkian period.

Van Hise,[73] in 1901, visited the northwest end of Blue Mountain, west of Florissant. Fibrolitic quartzite is found to be intricately intruded by granite.

About 2 miles northwest from Rocky the belt which Cross mapped as pure quartzite beds passing into quartzitic, micaceous, and fibrolitic schists was found to consist almost wholly of schists, gneisses, and granites of very great variety. By far the larger mass consisted of ancient gray and reddish banded gneisses and dark-colored pyroxenic and amphibolitic schists, cut through and through and injected in a parallel fashion by granite of a later age, and especially by pegmatite. So far as lithology is concerned, this mass seems to be identical with the Basement Complex.

Directly north of the road at Rocky post-office is quartzite interbedded with schist and cut and injected with granite, precisely as on Blue Mountain. Probably some of the schists associated with the quartzite are sedimentary, but it is difficult, if not impossible, to outline them. A small amount of limestone also is observed, making it possible that the quartzite observed has limestone facies.

If one were to examine the rocks adjacent to Rocky and consider the phenomena without reference to any other locality, he would doubtless conclude that all the schists, limestones, quartzites, and the banded gneisses, amphibolites, etc., belonged to the same series. Indeed, in this era there is no evidence to the contrary. However, all these rocks are intruded and metamorphosed by the Pikes Peak granite, and it would not be expected that unconformable relations between the quartzite and the gneisses could be observed. From analogy with the unconformable contacts at Coal Creek and South Boulder Creek canyons, however, where metamorphism is less intense, it is believed that the quartzite of this era merely rests unconformably upon the gneisses.

In the Royal Gorge of Arkansas River, from the mouth of the canyon up the river to Parkdale, there were observed a set of old gray gneisses, red gneisses, and black amphibolites intricately intermingled, all cut by Pikes Peak granite and other igneous rocks. The complex probably contains Archean schists and Algonkian granites, but it would be difficult to separate them.

South Boulder and Coal Creek canyons were again visited, and it was concluded that the Algonkian quartzite rests unconformably, with basal conglomerate, upon the granite of this area, and that the conformable gradation between quartzite and granite reported by Marvine and Lakes is an apparent one only, due to development of schistosity through readjustment along the contact plane. In both places it was possible to determine sharply the plane separating the schists derived from the metamorphism of the quartzite and conglomerate from that derived from the metamorphism of the granite. At South Boulder Creek pegmatite dikes cut the granite, but were not observed cutting the quartzite. At Coal Creek pegmatite cuts also the quartzite. Here also quartzite was found to reappear west of the basal granite, suggesting isoclinal folding or faulting, probably the latter.

Smith (W. N.),[74] in 1901, made a section across the belt mapped as Algonkian by Cross on Felchs Creek. The southwest contact of the quartzites was, so far as observed, always with intrusive granite, but on the northeast the contact is with the schist and is sharp and distinct. The contact is parallel to the bedding of the quartzite. Both quartzite and schist are cut by pegmatite and the quartzite by granite. The schist 50 yards away from the quartzite contact weathers in such a manner as to give it a conglomerate appearance. About one-quarter of a mile away, in the bed of Potato Creek, separated from the quartzite by intrusive granite, appear rusty schists, biotitic granites, and an intricate mixture of amphibolitic (?) schists, granites, and gneisses, cut by pegmatite, which have the appearance of belonging to the Basement Complex.

On Burnt Mountain south of Felchs Creek essentially the same facts were observed. In the bed of Ute Creek, which cuts this mass of quartzite almost in the middle, a black schist, or amphibolite (?), was found which had the same Basement Complex appearance as that found in the bed of Potato Creek. This was not far from the exposure of quartzite, and apparently below it.

Ball and Spurr,[75] in 1905, describe the pre-Cambrian rocks of the Georgetown quadrangle, situated in the center of the north half of

Colorado and lying between the meridians 105° 30′ and 105° 45′ west longitude and the parallels 30° 30′ and 30° 45′ north latitude. Georgetown, which is situated in the northwest corner of the quadrangle, is 40 miles west of Denver. The area lies on the east slope of the Front Range.

On Trout Creek, 30 miles southeast of the southeast corner of the quadrangle, little-metamorphosed Cambrian sediments lie unconformably on a rock complex showing approximately the same amount of metamorphism as the rocks of the Georgetown quadrangle, and presumably, in a general way, a southward extension of them. Hence the latter rocks are provisionally designated pre-Cambrian.

The rocks of the Georgetown quadrangle include schists and gneisses, much folded and often crenulated, which are intimately injected by dikes and irregular masses of a series of igneous rocks. The structure of these plutonic rocks varies from gneissoid to massive; and the rocks belong chiefly to the granitic and dioritic families. These gneisses and igneous rocks are cut by much younger dike rocks. So complex is the injection that five or six formations often outcrop in a single ledge, and inclusions within inclusions are common.

The succession of different pre-Cambrian formations, thus far recognized, is as follows:

1. Idaho Springs formation—schists and crystalline rocks (sedimentary).
2. Hornblende gneiss (mashed diabase).
3. Quartz monzonite gneiss.
4. Gneissoid granite.
5. Quartz monzonite.
6. Quartz-bearing diorite and hornblendites.
7. Rosalie granite (biotite granite).
8. Silver Plume granite (biotite granite).
9. Pegmatite and associated granite and granite porphyry.

The oldest of the gneisses, and indeed the oldest formation in the Georgetown quadrangle, is a series of intergrading biotitic and sillimanitic schists and gneisses and quartz gneisses. This series has been intensely folded and shattered by later intrusion. An excellent schistosity, with prevailing northerly dip, has been developed. Certain phases of this gneiss series show inclusions, which vary in shape, in proportion to the amount of stretching they have undergone during the process of metamorphism, from a normal pebble-like form to those which are more and more elongated till they appear as mere streaks or pencils. The material of these inclusions is uniform and appears in the field to be quartz, although the microscope shows also the presence of sillimanite. It is regarded as probable that such rocks represent metamorphosed conglomerates; and from this it is a natural step to regard other phases of the gneisses of very similar composition to the conglomeratic phases and interbedded with them, but without the inclusions, as having been very likely originally arkoses, sandstones, and shales. The interbanded relation of these different phases is favorable to this explanation; and certain highly siliceous bands have the composition of quartzites.

Interbedded with these schist series is a peculiar hornblende gneiss characterized by many facies. Coarse, pegmatite-like growths of quartz and epidote, epidote and garnet, garnet and quartz, and hornblende and plagioclase and lime silicate rocks occur. The wide variability of these rocks, often within short distances, together with their character, indicates that they are much-metamorphosed, impure calcareous sediments.

Dikes and sheets of a hornblende gneiss cut both the various members of the Idaho Springs formation and the older hornblende gneiss above mentioned. This usually has a well-developed schistosity, but is occasionally rather massive. It is probably mashed diabase.

The above formations are cut by a quartz monzonite gneiss whose hornblende has been altered partially or wholly to biotite.

The next oldest formation is a fine-grained, gneissoid, biotite-poor granite, often with plagioclase equaling orthoclase in abundance. The secondary development of microcline is characteristic.

A coarse-grained quartz monzonite, sometimes massive, sometimes sheared, and often porphyritic, cuts the above formations. This monzonite is the most extensive formation in the quadrangle, forming a batholith, from which the gneisses have quaquaversal dips.

A quartz-bearing diorite of approximately equal age with the last-mentioned rock occurs in small stocklike areas, more especially in the northern part of the quadrangle. This varies from a pure hornblende rock to a practically pure plagioclase rock. Certainly some of the hornblende is an alteration product of pyroxene.

The next youngest formation is the pink Rosalie granite, exceedingly coarse, the slightly smoky quartz and the biotite often being half an inch across and the pink or pinkish-gray feldspar an inch in length. This formation forms several small batholiths in the southern portion of the quadrangle. From the southeast corner of the quadrangle it extends eastward, outcropping in characteristic dome-like forms.

Cutting the preceding formations, with the possible exception of the last, is a massive porphyritic biotite granite, in some phases a granite porphyry, which has been called the Silver Plume granite. The phenocrysts, which are more or less perfect in form, and usually Carlsbad twinned, have, near the contacts with the older rocks, a marked parallel alignment. The unmashed condition of both phenocrysts and groundmass shows that this orientation is an original structure. This granite is quarried near Silver Plume.

Pegmatites of different ages are abundantly represented. These are intimately associated with, and probably genetically connected with, most of the various igneous injections enumerated. The most abundant of these is younger than all of the above-described formations, and is associated closely with and grades into granitic and aplitic facies. Rare minerals are not common in the pegmatites, although tourmaline, apatite, and garnet occur. Magnetite is also frequent in the pegmatite. While usually associated in the pegmatite with biotite and less often with muscovite, magnetite may be the only femic mineral. It sometimes occurs in quartz veins of pegmatitic origin. In places magnetite forms masses 4 inches in diameter and may constitute one-third of the pegmatite.

At three places in the quadrangle residuals of a well-sorted quartzitic sandstone were seen. A lithologically similar sandstone occurs in place south of the quadrangle, on the North Fork of the South Platte, above Shawnee. Beyond the fact that this sandstone contains pebbles of the coarse gray granite, its age is not known.

The gneisses and plutonics are cut by dike rocks, which are presumably post-Cambrian.

Fenneman,[76] in 1905, describes briefly the distribution and structure of Algonkian quartzite of South Boulder Canyon, in the Front Range of Colorado. Van Hise is followed in regard to relations to the Archean.

Darton,[77] in 1905, in connection with a discussion of the artesian wells of the central Great Plains, maps and describes the pre-Cambrian rocks of eastern Colorado.

Lindgren and Ransome,[78] in 1906, map and describe the geology of the Cripple Creek district of Colorado. They show a number of modifications of the earlier map, and further subdivide the pre-Cambrian rocks of the district. The most ancient rocks in the district are fibrolitic muscovite schists and fine-grained granitic gneisses, the former being possibly derived from sediments and the latter probably derived from granite. The gneisses are typically exposed in the streets of Cripple Creek and at the terminal station of the Colorado Springs and Cripple Creek District Railway. The schists may be well seen in Poverty Gulch between the Abe Lincoln mine and the railway trestle bridge, and near the station of the Florence and Cripple Creek Railroad in Cripple Creek. This gneiss was not separately shown on the older map, being included partly with the granites, which were mapped as a unit, and partly with the schist. Intrusive into the gneisses and schists is the Pikes Peak granite, prevailing over a large area in the district, especially in the vicinity of Squaw Mountain and Victor. A still later intrusive is the Cripple Creek granite, which occupies a considerable area extending westward from Anaconda beyond the bounds of the area studied, and well exposed along Cripple Creek in the vicinity of Mound. Another granite, called the Spring Creek granitic mass, is of comparatively small superficial extent, and its age with reference to the other granites is unknown. All are pre-Cambrian.

In the northwestern part of the district there has been found and mapped an area of a rock which is mainly an olivine syenite, though the mass exhibits remarkable range and variability in mineralogical composition. The olivine syenite is younger than the Pikes Peak granite, but is pre-Tertiary, for numerous diabase dikes genetically related to the syenite are covered or intruded by Tertiary eruptive rocks. A dike of anorthosite cuts the olivine syenite and is genetically related to it in a manner similar to pegmatite dikes in granite.

The schist, gneiss, Spring Creek granite, Cripple Creek granite, and olivine syenite together constitute a wedge-shaped area projecting into the Pikes Peak granite from the west. The center of volcanic disturbance is near the point of this wedge.

WET AND SANGRE DE CRISTO MOUNTAINS.

Schiel,[55] in 1855, describes the predominating rocks of the Sangre de Cristo Valley as a feldspathic granite, passing gradually into a gneiss on the right bank of the creek, the gneiss supporting a hard, shaly sandstone and a bluish brittle limestone.

Endlich,[64] in 1874, describes the region south of the Arkansas as consisting chiefly of granite. That forming the Sangre de Cristo Mountains differs in character and appearance from that of the Front Range. The Wet Mountains are regarded as eruptive. Gneiss occurs in this range at Hunts Peak and from there 6 or 7 miles to the northwest, and is regarded as metamorphic, although it weathers more like granite than a stratified rock. From the granite axis of the Sangre de Cristo the sedimentary rocks dip away both to the east and to the west. The eruptive granite of the Sangre de Cristo is the youngest of the region. Although the Sangre de Cristo Range is spoken of as eruptive, this is not considered to be so in the same sense that basalt is eruptive, but to imply that the granite by some vertically acting force has been thrown upward and may now be in contact with strata which were once above it.

Cope,[79] in 1875, states that in the Sangre de Cristo Mountains is stratified granite, which is either heavily bedded feldspathic porphyry or finely bedded hornblende gneiss.

Endlich,[80] in 1877, states that metamorphics compose the main bulk of the interior portion of the lower Sangre de Cristo Range, though at many places sedimentary beds and volcanic flows have obscured the relations. The highest peaks of the range are as a rule metamorphics, among which granites and gneisses are predominant.

These are associated with granites and gneissoid schists, associated with which are hornblendic, chloritic, and micaceous schists. Near Trinchera the sedimentary strata stand nearly on end and lie tipped up against the granite. At other places the granite protrudes through the Carboniferous. It is concluded that the metamorphics of the lower Sangre de Cristo are altered Silurian rocks. North of Arkansas River the Silurian formation occurs. From here it crosses the river toward the south and is last seen as such near the northern end of the Sangre de Cristo Range. In its stratigraphical relations it is conformable with the overlying younger formations wherever it has been there seen.

Endlich,[81] in 1878, states that while in the Sangre de Cristo the eruptive granite is the cause of the upthrow of the Carboniferous strata, nowhere in the sedimentary beds is found any case of intrusion. These granites are regarded as post-Carboniferous.

Emmons (S. F.),[66] in 1890, states that quartzites have been noticed connected with the Archean of the southern end of the Sangre de Cristo Range, which may be assumed to be the remnants of some Algonkian beds.

Cross,[82] in 1896, describes the geology of Silver Cliff and the Rosita Hills, Colorado. Gneisses and granites form the core of the Wet Mountains, on the west flank of which the district lies. The granites were first referred to the Archean, but are now believed to be Algonkian because of similarity to the granites of the Front Range in the Pikes Peak district, where similar granites are in part at least later than the Algonkian quartzites. The gneisses may be Archean. The gneisses strike northeast-southwest, with a northwest dip of between 45° and 90°. Neither top nor bottom of the series is determined. Volcanic rocks occupy a considerable area on the slopes of the Wet Mountains. No sedimentary rocks occur in the region.

Across the valley to the west the Sangre de Cristo Range is composed mainly of Carboniferous sandstones and conglomerates. At the east base is a profound fault, which has not been examined in detail.

Gilbert,[83] in 1897, maps and describes the geology of the Pueblo quadrangle, including part of Pueblo County and the southeast corner of Fremont County, Colo. Archean rocks of the Wet Mountain core occupy two small tracts in the southwestern part of the quadrangle. The more abundant kinds of Archean rocks are mica schist, mica gneiss, and granite. The schists and gneisses strike north to northwest, and are nearly vertical. Their origin is not known. The granite is intrusive in the schists and gneisses.

The Archean rocks are overlain unconformably by Paleozoic and Mesozoic sediments.

Hills,[84] in 1900, describes the geology of the Walsenburg quadrangle, in Colorado. The principal mass of the Greenhorn (Wet)

Mountains consists of coarse and fine grained granites and gneisses; hornblende, mica, and chlorite schist, and subordinate masses of garnet and epidote schist and occasional veinlike bodies of coarse pegmatite. The schistose rocks are more prominent at the southern extremity of the mountains than elsewhere, while the granite and gneissic rocks are more prominent in the main mass toward the culminating point. Their origin probably dates back to the Archean period. No further correlation is attempted.

Van Hise and Leith,[85] in 1905, give notes on the section along Arkansas River below Salida and the adjacent parts of the Sangre de Cristo Mountains. In going up the gulches toward the Sangre de Cristo Range to the south, bowlders of granite, greenstone, quartzite, and marble are abundantly seen, indicating the probable existence of a pre-Cambrian series of some variety and magnitude in this area. One of the gulches directly south of Salida was followed up to the Silver Lead mine. Well up on the slope, to the west of the road, quartzite, apparently dipping northeasterly along the slope, was found in place. Massive diorite forms most of the area south of the road, and many dikes are found in the quartzite. In going south—that is, up the mountain—the quartzite changes from a reddish feldspathic quartzite to a white vitreous one.

For further notes relating to the section along Arkansas River see pages 815–818.

PARK RANGE.

Marvine,[62] in 1874, describes the northern part of the Park Range as composed of a very distinctively and evenly bedded series of schists, gneisses, and granites, which have a strike nearly with the ridge, and a dip of 40° or 50° S.

Hague,[35] in 1877, describes the Park Range as made up of a system of highly crystalline rocks of Archean age. The later rocks form a very subordinate part of the uplift, rising not more than a few hundred feet above the plain, where they rest unconformably on the older series. The rocks of the Park Range resemble more closely those of the Colorado Front Range than they do the Medicine Bow, and are referred to the Laurentian. The range contains much structureless granite overlain by gneisses and schists similar to the series of the Colorado Range, but carrying more hornblende-bearing beds in the upper members. On the other hand, there are not wanting rocks which are characteristic of the Medicine Bow series and which were referred to the Huronian formation. The range has a monoclinal structure, with the prevailing dips to the west, while an outlying spur to the east indicates the existence of the eastern side of the fold.

KING,[86] in 1878, describes the Archean rocks of the Park Range. The crystalline body itself is a single anticlinal fold, of which that portion of the range south of Pelham Peak is the westerly dipping half. The easterly dipping half shows only in the extreme eastern foothills and in the projecting spur which lies between Big Creek and North Park. The main body, therefore, is the half of an anticline, the other half having suffered a deep downthrow, which has left only traces of the easterly dip. The series of Archean rocks involved in this fold are bedded granitic gneisses of uniform constitution and material but widely varied internal structure, hornblendic schists, and dioritoid rocks, besides limited quartzites. Of Archean eruptive rocks there are none, unless some obscure dioritic bodies are intrusive, and all the evidence points the other way.

EMMONS (S. F.),[87] in 1882, states that in the Mosquito Range are found granites, gneisses, and amphibolites. The granites are in most cases stratified and are of undoubted sedimentary origin. In other cases the evidence is less clear and they have the characteristics of eruptive granites. Within the masses of the normal granite occur large, irregular, veinlike masses, of secondary origin, corresponding to pegmatite. The gneiss is mostly mica gneiss. The amphibolite is less abundant than the gneiss and granite and occurs interstratified with them. Unconformably above these are quartzites which bear Primordial fossils belonging to the Potsdam.

EMMONS,[88] in 1898, describes the Archean rocks of the Tenmile quadrangle, in Colorado. These rocks outcrop to the east of the great fault—the Mosquito fault—running north of Leadville. They consist of granites, granite gneisses, mica schists, and amphibolites, with pegmatite veins traversing them in every direction. Gneisses and schists are the prevailing types.

A small patch of Cambrian sediment is found resting unconformably on the Archean to the east of the Mosquito fault.

SAWATCH AND ELK RANGES AND ADJACENT PARTS OF ARKANSAS AND GUNNISON VALLEYS.

HAYDEN,[89] in 1874, describes the Sawatch Range as a solid mass of granite, 80 miles in length by 40 in width, which has acted as a single wedge thrust upward, and thus causing the sedimentaries to incline from either side.

PEALE,[63] in 1874, states that on Massive Mountain the rocks are mainly gneissic, with alternations of porphyritic granite or granite porphyry, with seams of quartzite and hornblendic volcanic rock. On Eagle River, at the base of the section is gneiss, and above this is white quartzite.

ENDLICH,[64] in 1874, states that the granite of the Sawatch on the west side of the Arkansas is probably post-Silurian. This range has two kinds of granite that are peculiar to it and an older predominating one. Both of these are newer than the red, middle, and coarse-grained rock found in the Wet Mountains. The first of these varieties composes the main part of the range and constitutes its most prominent peak, Mount Princeton. Besides this, there is protogine and eruptive granite. Mount Ouray is composed in large part of hornblende rock. On one side the hornblende and granite are interstratified, the granite being regarded as intruded between the strata. The change from the granite to the hornblende rock is always abrupt.

LAKES,[90] in 1886, describes the Sawatch Range as consisting of gneiss and granite penetrated by volcanic dikes, with patches of Silurian, Carboniferous, and more recent strata resting on or uptilted against each flank. In the Aspen region are two granites, one the metamorphic granite of the Sawatch and the other a diorite and eruptive lava of the Elk Mountain system. On the granites are unconformably located the Cambrian strata, the base of which is quartzite.

CROSS,[91] in 1893, describes a series of hornblendic, micaceous, and chloritic schists on the eastern side of Arkansas River near Salida, Colo. In places these grade into massive rocks. They are cut by granitic and pegmatitic veins, as well as by dikes of porphyry. A detailed microscopical study leads to the conclusion that the rocks are a metamorphosed volcanic series. The whole constitutes a part of a single anticline. The schists are unconformably below the Silurian, and as the known Cambrian in Colorado is a thin series of quartzites and shales conformable with the Silurian, the Salida schists are considered as pre-Cambrian. The relations of the schists to the Archean complex are not exposed, but they are probably a continuation of the hornblende schists of Marshall Pass. Greenish schists are found at Tincup Pass, and near the town of Tincup are a highly crystalline marble interbedded with the green schists, and fine-grained gneissoid rocks, showing that metamorphosed sedimentary rocks do exist among the crystalline schists of the Sawatch Range. Taking into account all the facts, it is thought that the schists and massive rocks of the Salida section probably represent a great series of surface lavas, erupted in Algonkian time.

ELDRIDGE,[92] in 1894, maps and describes the Crested Butte quadrangle, in the Elk Mountains, Colorado, and finds that on the northeast and southeast corners of the district are Archean areas. These consist mainly of granite and granite gneiss, with local developments of gneiss and schist.

LAKES,[93] in 1897, sketches the geology of the Gunnison gold belt, in Gunnison County, Colo., from Cebolla River on the west to the head of Taylor Park and the Sawatch Range on the east. The northern part of the area is included in the granitic system of the Sawatch Range. The southern part is occupied by schists and gneisses, underlain by coarse massive granite. The schists and gneisses are of pre-Cambrian age, but whether Algonkian or older has not been determined. The contact of the schists and gneisses with the underlying granite is an eruptive one, the granite containing fragments of the schist, giving the impression that the schists had been floated up on an underlying molten or semimolten sea of granite. Cutting the schists are occasional dikes of diabase and possibly basalt and andesite, and resting on the eroded edges of the schists are various later overflows of andesitic breccia, rhyolite, trachyte, and basalt.

Spurr,[94] in 1898, maps and briefly describes the Archean [a] granite of the Aspen district of Colorado. This is unconformably below and in direct contact with sediments of upper Cambrian age.

Van Hise and Leith,[85] in 1905, made a reconnaissance along a part of the Sawatch Range. On the west flank of the Sawatch, about 2 miles north of Tincup, fine-grained fissile mica schists, taken to be altered sediments, were observed. Some of the schists have quartzitic aspects. The marble described by Cross in this vicinity was not visited. Southeast of Tincup, on the road to St. Elmo, typical ellipsoidal basalts and green schists, similar to those of the Keewatin of the Lake Superior region, were found to extend nearly to the top of the Sawatch divide. At the divide the coarse Sawatch granite intrudes the green schists.

The area about Salida, described by Cross, was examined. About 5 miles southeast of Salida, along the Arkansas River, Paleozoic sediments may be seen dipping to the southeast, down the river, and resting upon a crystalline series taken to be pre-Cambrian. This consists of fine-grained novaculitic quartzite, intruded and interbedded by a porphyry with flow structure and dark felsitic phases, so closely resembling the quartzite that it is difficult to tell in some places where the quartzite ends and the porphyry begins. The quartzite dips at about the same angle as the Paleozoic limestones above. The plane of contact is apparently an even one, and there is to be seen no evidence of any conglomerate or structural unconformity. However, the porphyry may be traced within a few yards of the limestone contact, where it ends abruptly. This fact, together with the general metamorphosed aspect of the quartzite, is taken to indicate its probable unconformity with the overlying Paleozoic sediments. However, it is also possible that the lower portion of the Paleozoic has been invaded by acidic intrusives which have reached a certain horizon and metamorphosed all rocks beneath this horizon. In this case the supposed

[a] The term Archean is evidently used in the sense of pre-Cambrian.

pre-Cambrian quartzite associated with the volcanics is really Paleozoic.

Van Hise visited the Sedalia mine, about 5 miles north of Salida, on Arkansas River. It is located in micaceous and quartzose schists cut by granite dikes. Near the dikes large porphyritic garnets have developed in some places, and in other places actinolite, which may be seen altering into asbestos. The schist is broken into a massive breccia in the mine proper. Intrusive diorite is also seen. In returning to Salida along the cliffs he observed that the dioritic material becomes much more abundant, and is indeed more abundant than the schists, although the quartzitic schist was found at intervals as far as the section was followed—that is, about 2 miles southeast of the mine—where a reentrant carries the exposures back to the east a mile or more. The diorites all seem massive and are probably all intrusive, like the diorite dikes seen at the mine. The dioritic material sometimes becomes schistose. Where least metamorphosed the schist approaches a novaculite in nature.

See further notes of Van Hise and Leith on adjacent parts of the Sangre de Cristo Mountains, this chapter, page 814.

GRAND AND GUNNISON RIVERS.

Schiel,[55] in 1855, states that along Coochetopa Creek and Grand River valleys are granite, gneiss, shale, and mica slate.

Peale,[63] in 1874, states that adjacent to the Gunnison a section has at its base rust-colored granite, above which is mica schist, and over this quartzite and sandstone.

Stevenson,[65] in 1875, states that at several localities along the Grand and Gunnison is a peculiar, regularly laminated gneiss which resembles a micaceous sandstone. It always occurs directly under the sedimentary rocks and no similar formation occurs lower down. It is clearly unconformable to the great mass of schist and gneiss, though precisely like them in its changes. In consideration of all the circumstances, one can not resist the temptation of regarding it as belonging to a later series.

Peale,[95] in 1876, describes Archean rocks as occurring along and near the gorges of Eagle and Gunnison rivers. The rocks of Eagle River are known to be pre-Potsdam, because at the head of the stream such rocks rest upon them. On Gunnison River the Archean rocks are gneisses and schists. The presence of Dakota beds here resting upon the Archean is supposed to prove that in pre-Cretaceous times this area was above sea level.

Peale,[96] in 1877, describes the Archean rocks of Grand River. These occur in limited areas throughout the district between parallels 37° 52′ and 39° 15′ and meridians 107° and 109° 30′. They are generally confined to the courses of streams flowing in canyons. In many places the schistose character is very distinct and the bedding clearly seen, but in most cases no traces of bedding were seen, the rocks being granitoid. From the number of exposures noticed it is evident that the rocks underlie the entire district, although from the limited and isolated exposures it was not possible to trace connections from one place to another. The oldest sedimentary beds resting upon these rocks are Carboniferous or pre-Carboniferous, showing that they are at least pre-Carboniferous, but it is believed that they are pre-Silurian. Along the Gunnison occur outcrops of quartzitic layers with softer red and gray gneissic layers. On the Little Dolores are mica schists and quartzites dipping northeast at angles of 60° to 70°. As to the origin of these rocks it is said: They were once deposited as sediments. Whence were their materials derived? We have no data from which we are able even to guess what was the extent of the Archean continent, or what its character was. From the fact that in the Grand Canyon of the Colorado similar rocks are found below the Potsdam, and from the profundity of their metamorphism, it is believed that these crystalline rocks are Archean.

SOUTHWESTERN COLORADO, INCLUDING THE SAN JUAN, NEEDLE, AND LA PLATA MOUNTAINS.

ENDLICH,[97] in 1876, describes the Quartzite (now known as Needle) Mountains. Near the northern border and toward the middle, quartzites and schists predominate, while granite appears toward the east and south. An attempt is made to prove a gradation between quartzites, granites, and schists. The Devonian strata were deposited on the granitic strata conformably.

ENDLICH,[81] in 1878, gives a general discussion of the formations of Colorado. In preference to the word Azoic the word Prozoic is used. Belonging to this group, in southern Colorado, is an extensive series comprising gneisses, granites, various schists, and diorites. Of these the first named appear to be the oldest, as may be inferred from the relations to the granites more particularly. The schists are in subordinate quantity. It often is a matter of difficulty to discriminate between the Prozoic and the next group of metamorphic rocks. This latter is the most varied and enormous in its development. In several instances localities may be observed where the transition from undoubted sedimentary into metamorphic beds is evident. A large part of the granites in southern Colorado is regarded as metamorphosed Silurian, Devonian, and in rare instances even Carboniferous strata.

COMSTOCK,[98] in 1883, states that in San Juan County there are no rocks of Archean age. The granitic and quartzitic series of Animas River are regarded as metamorphic and said to be of Upper Silurian or Devonian age.

Comstock,[99] in 1887, describes the metamorphic series in southwestern Colorado as probably Silurian or Devonian. This series is susceptible of division into an upper or granitic division and an underlying quartzitic formation. The quartzitic group is exposed in the Animas Canyon below Silverton, forming a line of jagged peaks to the eastward, the Needle Mountains. Whenever the quartzite is well uncovered the more recent granites are usually traceable along the flanks of the belt. The geological map brings out no apparent system in the metamorphic rocks.

Lakes,[100] in 1889, describes, on the Mears road, south of Ouray, as succeeding the Carboniferous limestone, a thickness of 13,000 feet of distinctly stratified and hard vitreous quartzites, slates, and schists. Part of these may belong to the Silurian and Cambrian, but as these combined rarely attain in Colorado a thickness of 1,000 feet, so great a body is extraordinary and suggests that the lower part of it may, as in Canada, belong to the Huronian or Laurentian, upper divisions of the Archean not elsewhere represented in Colorado. The dip of the quartzite is about 75° N. The uplifted crests have been deeply eroded and in the hollows so formed rest the massive volcanic breccias.

Van Hise,[38] in 1889, made observations along the Animas, the railroad being followed from below Needleton to Silverton, a distance of about 17 or 18 miles. As mapped by Endlich on Sheet XV of the Atlas of Colorado, this course is situated, with the exception of 5 or 6 miles, in the quartzite area. Quartzites occur for a little more than 2 miles in the vicinity of Elk Park, in the middle of the area mapped as quartzite. The granitic area was found to be a most intricate complex of massive granite, coarse and fine, white and black banded gneiss, and black hornblende schist or gneiss in dikelike forms. The strikes and dips vary greatly, although for the most part they are high, running from 75° to 85°. At one place the dip of the schistose structure was observed to be as flat as 10° or 15°.

On neither side of the quartzite area was evidence seen of a transition into granite; nor were the quartzites and granites seen in contact; they were found, however, a few paces apart. At the southern boundary, while the two rocks were not actually found in contact, there is a marked discordance in the strike and dip of the schistose structure of the granite and of a series of sharply folded anticlines and synclines of quartzites which are adjacent to the granite.

Bearing upon the question of the position of the quartzitic series with reference to the fossiliferous rocks is the occurrence south of Ouray, along Red Mountain Creek and one of the branches of the Uncompahgre, of a great series of slates, quartzites, and conglomerates, with high dips and repeated by folding, which are in lithological character identical with the quartzites south of Silverton. Just south of Ouray the shales and limestones of the Devonian are found in almost horizontal position upon the upturned edges of the slates and quartzites. This unconformity, in the distance at which it may be observed and in the masses of rocks exposed, is remarkably handsome. In apparent conformity above the Devonian at Ouray is a thick Pennsylvanian Carboniferous formation. In the distance of about 5 miles in which this quartzite series is exposed a slate band is found five times. In going north the dips are first south and then change to the north, in which position they continue until the Carboniferous appears. All this suggests that we have here to deal with a folded series, and not one necessarily of very great thickness, although probably several thousand feet thick. As Ouray is only a few miles from Silverton, the argument of analogy makes it probable that the similar plainly fragmental slates and quartzites south of Ouray are the equivalent of the quartzites of Elk Park. The facts bear against the probability of a transition from the Devonian into the quartzitic series of the latter place. The one occurrence in which this transition is definitely asserted is perhaps a case of a recomposed rock resting upon a crystalline one. Similar occurrences have often been described.

Emmons (S. F.),[66] in 1890, states that on the north slope of the San Juan Mountains, near Ouray, are more than 10,000 feet of closely folded quartzites, conglomerates, and slates of pre-Cambrian age, and it is believed that the quartzite peaks in the southern portion of this region are probably composed of the same series of rocks. These are referred to the Algonkian.

Cross,[101] in 1899, maps and describes the geology of the Telluride quadrangle, Colorado, and briefly sketches the geology of the San Juan region, of which the Telluride quadrangle is a part.

Along Canyon Creek north of Stony Mountain is a small body of upturned quartzites with an intercalated rhyolite sheet, which have been referred to the Algonkian. The quartzites are coarse and grade into fine conglomerate.

Cross and Spencer,[102] in 1900, describe Algonkian rocks occurring in the center of the Rico Mountains of Colorado. They consist of quartzites, quartzitic schists, and biotite and actinolite schists. The exposed thickness of the quartzites is more than 350 feet, and probably as much as 500 feet. The relations of the quartzites to the schists have not been ascertained. The schists and quartzites of this area are similar in every way to the series of rocks exposed in the upper part of Animas Canyon and in adjacent portions of the Quartzite or Needle Mountains, where they have been referred to the Algonkian by Emmons and Van Hise. The quartzite of the Rico Mountains is directly along the strike of the great quartzite belt in the Animas Canyon and Needle Mountains area.

Howe,[103] in 1904, describes green schists in the pre-Cambrian of the Needle Mountains, in San Juan and La Plata counties, southwestern Colorado. They comprise massive and schistose, granular, and porphyritic metagabbro and areas of mashed granitic intrusives and other schistose rocks, presumably altered quartzites. No evidence of surface origin is noted in the igneous rocks. The greenstones antedate the Algonkian sediments to the north, as shown by the pebbles contained in the Algonkian conglomerate, and have an older aspect than the other rocks of the neighboring areas. They are therefore assigned to the early Algonkian. Attention is called to their similarity to the greenstones of the Menominee and Marquette districts of Michigan and to rocks near Salida, Colo.

Cross, Howe, and Ransome,[104] in 1905, map and describe the geology of the Silverton quadrangle, in southwestern Colorado. Schists of supposed Archean age form the walls of the canyon of Animas River from the monzonite stock below Silverton to a line a short distance beyond the southern boundary of the quadrangle, at Whitehead Creek, where they come in fault contact with Algonkian quartzites. They are exposed in an irregular area that extends from the canyon eastward, from which the volcanics have been removed by erosion, and in Cunningham Gulch down nearly to Stony Creek. The rocks are all strongly foliated and also have a banded appearance, which is often due to the alternation of dark and light constituents. The schistosity, which seems to correspond with the banded arrangement of mineral particles, has within this area a northeast-southwest strike and a nearly vertical attitude, except in the lower part of Animas Canyon, where the dip flattens out and the schistosity becomes almost horizontal. This schist section, while varying in petrographic detail from place to place, possesses no clearly marked divisions which it is practicable or desirable to recognize as cartographic units. The schists are cut by bosses of granite and their apophyses, as well as by numerous basic dikes. These intrusives are undoubtedly older than the first Paleozoic sediments, but may be younger than the great Algonkian series of the adjacent Needle Mountains.

Algonkian quartzites, slates, or shales appear in Uncompahgre Canyon, with dips varying from vertical to less than 30°, and on the eastern side of Ironton Park at the mouths of Albany and Brooklyn gulches. The base of the Uncompahgre series is apparently near its southern border and the top near Ouray. The structural relations of the Algonkian section in the Uncompahgre Valley to that of the Needle Mountains can not now be ascertained, for between them occur the older schists or the Tertiary volcanics.

Cross, Howe, Irving, and Emmons,[105] in 1905, describe the Needle Mountains quadrangle. Gneisses and schists exhibiting profound metamorphism, but shown by their composition to be probably igneous, are unconformably below quartzites of the Needle Mountains group (Algonkian), and are assigned to the Archean. These rocks follow the canyon of the Animas from a point to the west in the Engineer Mountain quadrangle, in a band 3 or more miles wide, northward to the Algonkian quartzites near Elk Park, with an arm extending northeastward from the mouth of Ruby Creek to Balsam Lake. They are interrupted at several places by intrusive bodies of granite. North of the zone of Algonkian rocks the schists again appear at the mouth of Whitehead Creek and extend continuously along the northern border of the quadrangle from near Molas Lake to Beartown. These exposures continue for a few miles northward in the Silverton quadrangle until covered by sedimentary or volcanic rocks.

Provisionally assigned to the Algonkian are the Irving greenstones, consisting of a complicated series of schists, greenstones, and subordinate quartzites, a portion of which is prominently exposed in the southeastern part of the quadrangle and of which Irving Peak is composed. In some respects similar to the Archean schists of Animas Canyon, the Irving greenstone must, nevertheless, be distinguished from them on account of the lesser degree of metamorphism, the distinctive character of certain of the more massive members of the series, and the presence of sedimentary rocks. The actual base of the Irving has nowhere been seen, for on the west it has been found only in contact with the Eolus granite, while to the east it appears to be in many cases in fault or shear contact with the Vallecito conglomerate or the Uncompahgre quartzite.

To the Algonkian are assigned the Uncompahgre quartzite and the Vallecito conglomerate, together forming the Needle Mountains group, with a thickness of not less than 7,000 feet. The Vallecito conglomerate, exposed at Vallecito Creek and Pine River, contains pebbles derived from the Irving greenstone. To the east of the quadrangle the conglomerate grades up into conglomeratic quartzite similar to that at the base of the Uncompahgre quartzite. The Uncompahgre quartzite crosses the quadrangle in its northern portion.

The lowest member of the Paleozoic is quartzite, probably of Upper Cambrian age, resting unconformably upon the rocks here described.

Cross, Howe, and Irving,[106] in 1907, map and describe the geology of the Ouray quadrangle, in southwestern Colorado. Southward from Ouray, on Uncompahgre River, are quartzites and slates of the Uncompahgre formation of the Needle Mountains group, assigned to the Algonkian. They are limited on the north by a fault which brings them into contact with Paleozoic sediments. On the east they are covered by the San Juan tuff and on the west by the oldest Paleozoic sediments. The formation is exposed farther south, in the Silverton quadrangle, for nearly 2 miles.

SUMMARY OF PRESENT KNOWLEDGE.

COLORADO, GENERAL.

The following general summary is furnished by Whitman Cross:

Introductory note.—In using the term pre-Cambrian it is to be noted that the only Cambrian sediments known in Colorado belong to the upper Cambrian or Saratogan series and are very thin in all described localities. It is, therefore, not impossible that some of the massive, unmetamorphosed granites and other igneous rocks may be of early Cambrian age.

General statement.—The pre-Cambrian rocks form a large part of the Front and Park ranges and of the Wet, Sangre de Cristo, Sawatch, and Needle (Quartzite) mountains, and they further appear in the canyon of the Gunnison River and locally beneath the sediments of the Uncompahgre Plateau. Their distribution is, in the main, quite correctly shown by the Hayden map of the State.

It was the view of the Hayden geologists, as of most of their contemporaries, that these ancient granites, gneisses, and schists represented highly metamorphosed sediments; the more massive and coarsely crystalline the granite the more extensive the metamorphism was believed to be. This idea was applied by Peale, for example, to the granite of Pikes Peak, by Marvine to granites and gneisses of the northern Front Range, and by Endlich to the granular rocks of the Needle Mountains. This conception was a common one at the time of the Hayden Survey, but it has been shown to be erroneous, so far as the massive granites and many of the gneisses, at least, are concerned.

Within the last twenty-five years the pre-Cambrian complex has been studied with some care by various investigators, but in a few localities only. The numerous routes of travel now crossing the mountains have, however, permitted the observation that the results of special studies apply in general to the whole complex. The broad conclusion can, therefore, be drawn with safety that the ancient rocks mapped by the Hayden and contemporary geologists under the one rubric "Metamorphic" fall into four main categories:

1. A complex of gneisses and schists, the oldest rocks of the mountains.

2. A complex of basic igneous rocks, now for the most part changed to greenstone schists and gneisses.

3. A series of quartzites, slates, schists, and conglomerates, all of undoubted sedimentary origin.

4. Massive igneous rocks, chiefly granitic, occurring in large and small bodies, cutting the gneisses and sediments in some places and elsewhere showing by their comparatively unmetamorphosed con-

dition that they presumably form the most recent of the four categories mentioned.

These four classes of rocks will now be considered separately:

Ancient gneisses and schists.—Gneisses and schists of various sorts and in complex relations, throughout similar to the typical Archean or basal complex of many other regions, are common in Colorado. The gneisses are often of granitic composition, sometimes more nearly dioritic, and dark amphibole or pyroxene gneisses and schists are very abundant. In some localities the dark basic rocks cut the more siliceous and feldspathic gneisses in intricate fashion, but have been greatly metamorphosed into schistose forms.

The origin of some of the gneisses from igneous rocks is clearly shown in some places, and it has not been established that any of them are metamorphosed sediments.

Greenstone schists and allied rocks.—Ancient greenstone schists comparable in most respects with the Quinnesec schist of the Lake Superior region have been found in two districts of Colorado. The first to be discovered was the series of peculiar schists near Salida described by Cross. These schists reach a thickness of nearly 10,000 feet and consist chiefly of schistose or gneissoid rocks resulting from the metamorphism of basic igneous rocks of basaltic or diabasic character. This complex is not wholly basic and some of the schists were derived from siliceous lavas or intrusives.

The second area of basic schists is composed of the Irving greenstone of the eastern Needle Mountains, which is referred to in another place. These schists specially resemble the Lake Superior greenstones in petrographic details and in the iron ores which were formerly associated with them, as shown by the pebbles in the succeeding sediments.

It seems probable that other areas of such rocks will be found in Colorado, but their direct correlation may be a difficult matter. The basic rocks of the Encampment district in Wyoming, described by Spencer, would seem to belong to the same general group as those here mentioned.

Pre-Cambrian sediments.—The pre-Cambrian sediments of the Needle Mountains, Uncompahgre Canyon, Rico Mountains, and Front Range are preserved in such considerable thicknesses as to show that once there must have been a very extensive development of these rocks in Colorado. It must be questioned whether the rocks referred to occasionally in the older literature of Colorado as quartzites or sandstones and represented as in association with gneisses and schists are really of sedimentary nature in many cases. Even if they are such, it is probable that they are much older than these distinct sediments which form normal groups of conglomeratic, sandy, or shaly deposits, now much metamorphosed, yet sharply distinguishable from the schists and gneisses which occur near them. The complex folding and metamorphism which these ancient sediments have undergone, the great orogenic disturbances, and enormous erosion, all of which preceded the upper Cambrian epoch of sedimentation, seem to warrant the conclusion that these older clastic rocks are of Algonkian age.

Whether the Needle Mountains group of southern Colorado can be surely correlated with the quartzites, etc., of the Front Range is open to question. It is a natural suggestion that the former may be equivalent to some portion of the Grand Canyon section of Algonkian sediments. The quartzites of the Front Range doubtless belong to one series, and their structural relations indicate that they may reappear either to the north or to the south of Colorado, within or on the flanks of the Rocky Mountain ranges.

Massive igneous rocks.—Wherever any considerable area of Archean gneisses and schists in Colorado has been closely examined it has been found to be penetrated by intrusive igneous rocks, often in a very intricate interlacing of different varieties. The rocks here referred to are either unmetamorphosed or but locally affected. They do not penetrate the early Paleozoic sediments, where the latter are preserved, and hence must be considered as pre-Saratogan, if not strictly pre-Cambrian. In the Pikes Peak quadrangle the great granitic masses have intrusive relations to the Algonkian quartzites, and similar, though less marked, relations exist in the Needle Mountains, so that at least a part of these massive rocks must be considered as of Algonkian or post-Algonkian age.

Among these intrusives, granites are by far the most common, but syenite, monzonite, diorite, and gabbroic rocks are known as occurring in large bodies. A batholith of gabbro several miles in diameter occurs in the Animas Valley, lying in the Engineer Mountain quadrangle.

In addition to the masses of considerable size just referred to, there are countless dikes of pegmatite, aplite, and granite on the one hand, and of diabase, pyroxenite, and other basic rocks on the other, with many intermediate kinds, which are not known to cut the Paleozoic sediments. These basic dikes are distinct from the more ancient ones now represented by amphibolitic schists which are common in the Archean complex in intricate relations with schists and gneisses.

FRONT RANGE.[a]

By far the greater portion of the Front Range of Colorado is composed of the typical basement complex, or Archean, and intrusive granites. In the central part of the range gneissoid granites are pre-

[a] By the authors.

dominant, but in some places along the eastern border this gneissoid granite varies into a great series of completely crystalline schists. Taking schistose structure for bedding, King estimated the thickness of the series at Clear Creek to be 25,000 feet. However, the structure is, without doubt, foliation, and the figure given only serves to show the extent of the schistose area.

In the district of Coal, Boulder, and Thompson creeks, on the east side of the range, is a narrow belt of mica schists, quartzites, quartz schists, and schist conglomerates, containing abundant pebbles of white quartz and fewer of gneissoid granite, the thickness being unknown; but if foliation corresponds to bedding the maximum thickness is at least 1,000 feet. The clastic character of this series is unmistakable. The higher members of the series are quartz schists alone, but lower down mica schists and quartz schists are interstratified with beds of conglomerate. At the base the mica schists become interlaminated with gneiss, which rock becomes more and more abundant, and upon Coal Creek pegmatitic granite veins cut them. Nowhere between the clastic and the gneissoid series has any structural discordance been discovered, there appearing to be a somewhat rapid gradation between them. The series has been subjected to such intense dynamic action as to almost entirely obliterate the clastic characters, with the exception of the schist conglomerates, and even in these the matrix is a completely crystalline schist, the only unmistakable evidence of the sedimentary character being the greatly mashed and flattened pebbles. By careful observation, however, the sedimentary schists may be sharply delimited from the gneisses. Because of the lithological separation which is possible, the presence of schist conglomerate near the base of the clastic series, and the fact that the clastic series is not cut by pegmatite intrusives to the same extent as the lower gneissoid series, it is believed that the sediments rest unconformably upon the gneisses and granites. In this area the next overlying series is Triassic, but elsewhere in the Front Range little-metamorphosed upper Cambrian sediments overlie the crystalline rocks. For this reason the crystallines may be either pre-Cambrian or early Cambrian, but from their lithological character it is believed that they are pre-Cambrian. The gneisses and granites are further classified as Archean and the quartzite series unconformably above as Algonkian.

In the Georgetown quadrangle, west of Denver, Spurr and Ball find schists and gneisses cut by seven different intrusions. The oldest schist, named the Idaho Springs formation, is believed to represent a much altered sediment. The associated hornblende gneiss represents a metamorphosed impure limestone. The rocks are provisionally assigned to the pre-Cambrian because Cambrian sediments are found to overlie them to the southeast of the quadrangle. The oldest gneiss is also provisionally correlated by Ball and Spurr with certain schists of the Cripple Creek region, classed provisionally as Archean by Cross.

In the Pikes Peak district Cross describes numerous masses of quartzite included in and cut by granite. The largest of these, in Wilson Park, is 4,000 feet thick, stands on edge, and is exposed for 5 miles along the strike. Other large masses occur in Cooper and Blue mountains. These quartzites and the intersecting granite, which occupies a far greater area than the quartzites, Cross refers to the Algonkian.

Van Hise believes that some of the gneisses and amphibolitic schists associated with the quartzites northwest of Florissant, in the Pikes Peak quadrangle, are older than the main masses of intrusive granites, and probably belong to the basement complex or Archean. Rocks of a similar old aspect were observed by W. N. Smith in the Felch Creek section.

Crosby calls attention to the general even character of the granite floor of this area and holds that it marks the end and not the beginning of base-leveling processes.

WET AND SANGRE DE CRISTO RANGES.[a]

Pre-Cambrian rocks, mainly granite, gneiss, and mica schist, form the Wet Mountains. The granite is intrusive into the gneiss and schist and is correlated by Cross with Algonkian granites of the Front Range. The origin of the mica schists is not known.

Granite, gneiss, and schist are also found in the axis of the Sangre de Cristo Range. Dark amphibolite and other dark schists occur in Hunts Peak. Cross concludes that the "eruptive granite" of the Hayden map is probably of post-Algonkian age. Quartzite, taken to be Algonkian, has been observed by Emmons in the southern part of the range and by Van Hise and Leith on the north flank south of Salida. Cross concludes that the southern part of the range near Silver Cliff is composed mainly of Carboniferous sandstones and conglomerates.

PARK RANGE.[a]

The Park Range is composed of rocks of pre-Cambrian age, consisting largely of granite associated with gneiss and schist and amphibolites, with pegmatite dikes. The rocks in general resemble those of the Front Range. The prevailing dips of secondary structure are toward the west. In the northern part the dip is 40° to 50° S. Hague and King viewed the range as representing the west half of an anticline, the eastern half of which has been faulted down. Cam-

[a] By the authors.

brian sediments rest unconformably against the crystalline rocks, which are therefore pre-Cambrian, but scarcely to be more closely correlated with present evidence.

SAWATCH RANGE AND ADJACENT VALLEYS.[a]

The Sawatch Range is composed mainly of granites, gneisses, and schists. Near Salida, Marshall Pass, and Tincup Pass the schists are hornblendic, micaceous, and chloritic, believed by Cross to be a series of metamorphosed Algonkian lavas, though containing at Tincup Pass highly crystalline marble. Abundant quartzites, interbedded with schistose acidic porphyries and diorities, were observed by Van Hise and Leith in the Salida area. Some of the green schists observed by Van Hise and Leith along Tincup Pass are thought to be metamorphosed ellipsoidal basalts very similar to those characteristic of the Keewatin series of the Archean system of the Lake Superior region.

The presence of limestone and quartzite in the pre-Cambrian schists of the Sawatch and adjacent valleys, making up, in the case of the quartzites, the major part of the series, suggests the Algonkian age of this part of the series, but the granites and the other gneisses and schists may be of the same or different ages. Sufficient work has not yet been done to separate them lithologically or structurally. The best that can be done is to refer the entire complex to the pre-Cambrian.

GRAND AND GUNNISON VALLEYS.[a]

Here are considerable areas of granites and gneiss of pre-Cambrian age. In the Gunnison Valley Peale[b] reports the existence of quartzitic layers with the gneiss. Quartzites, taken to be of pre-Cambrian age, are abundant south of Iola on Gunnison River.

NEEDLE MOUNTAINS AND VICINITY.

The following summary for Needle Mountains and vicinity has been furnished by Whitman Cross:

General statement.—The area of pre-Cambrian rocks occurring in the Needle (Quartzite) Mountains and Animas Canyon of southwestern Colorado has been studied in the Needle Mountains, Engineer Mountain, Silverton, and Durango quadrangles. The extreme eastern part has not been examined.

The Hayden map represents the northern and central part of the Needle Mountains as composed of "metamorphic Paleozoic" ("M P"), while bordering the mountains on the east and south and extending down the Animas Canyon is an irregular area of "meta-

[a] By the authors.

[b] Peale, A. C., Geological report on the Grand River district; Ninth Ann. Rept. U. S. Geol. and Geog. Survey Terr., 1877, pp. 29–101, with atlas sheets.

morphic granite" ("M G"). The study of these formations by Cross and Howe has shown that the Hayden distinction has no meaning. The rocks are divisible into—

1. The Archean gneisses and schists.
2. A group of greenstones, with derived gneisses and schists, and intimately associated with very subordinate quartzites.
3. A group of conglomerates, quartzites, and shales or slates, called the Needle Mountains group.
4. Intrusive and still massive granite and gabbro bodies of large size, with many smaller dikes.

Archean gneisses and schists.—The oldest rocks of the area are the gneisses and schists, most prominently displayed in the Animas Canyon. These are mainly granitic or dioritic gneisses and amphibolitic schists. They are exposed in a thickness of many thousand feet in the canyon section, the structure being complex and defying accurate estimate of the thickness. Some of the gneisses show evidence of a derivation by crushing and recrystallization from igneous rocks, granites, or diorites. No demonstrable sedimentary rocks have been found in the complex.

The dark amphibolitic schists occurring about the mouth of Cascade Creek have been intruded by a biotite granite in an extremely intricate manner. Over several square miles the schists are either split in thin strips and layers, a few feet or perhaps only a few inches thick, or the brecciation has been irregular, the intruded granite being often in equal or even subordinate amount. In some parts the granite is nearly free from inclusions and becomes massive.

The gneisses and schists are interrupted in the heart of the mountains by granite or the Needle Mountains group of sediments, but reappear in the canyon below Silverton and extend easterly under the volcanic rocks an unknown distance.

Irving greenstone.—This formation is exposed in only one area in the southeastern part of the mountains, in the valley of Vallecito Creek. Petrographically the rocks consist of hornblendic metadiabase, massive in texture, but grading into typical greenstone gneisses and schists almost indistinguishable from the Quinnesec schist of the Menominee district on Lake Superior. The rocks are intricately folded and the thickness of their visible section can not be determined, but it is probably 2,000 or 3,000 feet at least.

Typical quartzite is locally found with these greenstone schists, but whether as a contemporaneous deposit or as an infolded fragment from a separate formation could not be satisfactorily determined.

The relations of the Irving greenstone to the gneisses and schists of the Animas Canyon section can not be ascertained, as they are separated by a huge granitic mass. Contact relations and an abundance of greenstone pebbles and bowlders in the basal conglomerate of the Needle Mountains group establish the relative age of these two formations.

Needle Mountains group.—The sedimentary rocks observed by Endlich, and much later by Van Hise, form a very important element of the Needle Mountains and have received the name Needle Mountains group. They occur in a highly compressed and faulted synclinorium forming a wide crescentic zone through the northern and eastern part of the mountain group. Many rugged peaks exceeding 13,000 feet in height occur within this zone. While the prominent quartzites gave rise to the name used by the Hayden geologists for these mountains and to the distinction of the large part of the area on the map as "metamorphic Paleozoic," the sediments really occupy but about half of the area thus designated, the remainder being chiefly a very massive granite.

The Animas Canyon section of the Needle Mountains group, some miles long, which was studied by Van Hise in 1889, exhibits only quartzites and slates or shales, the outer boundaries being very steeply inclined faults, in general parallel to the complex folds and faults of the geosyncline. Quartzite in very massive hard banks, often conglomeratic, but with very small pebbles, is the predominant rock. Dark shale, now variably metamorphosed to slate, constitutes the minor part of the section.

This complex of shales and quartzites has been called the Uncompahgre formation, since it is apparently equivalent with the lithologically identical succession of pre-Cambrian beds shown in the Uncompahgre Canyon, on the northern side of the San Juan Mountains, some miles away.

The lower formation of the Needle Mountains group is exposed in the Vallecito Valley, in the southeastern part of the Needle Mountains quadrangle, and extending a few miles east into the valley of Pine River. It is preeminently a conglomerate of coarse texture, as a rule, and has been named the Vallecito conglomerate. Its base is seen resting unconformably on the Irving greenstone, and the lower part of the conglomerate is largely made up of greenstone pebbles. Upward, quartzite and various schists are more and more abundant among the pebbles. Small pebbles of jasper and hematite or magnetite are also abundant in the upper part of the Vallecito conglomerate, testifying to a former iron-bearing formation which seems probably to have been associated with the Irving greenstones. The thickness of the Vallecito conglomerate has not been measured, but it is 2,000 feet or more.

Intrusive granites and other rocks.—The high central peaks of the Needle Mountains, including Pigeon Peak and Mount Eolus, are wholly of a massive granite belonging to a huge batholith exposed over many square miles and disappearing beneath the Paleozoic section to the south. Other minor batholiths of granite occur cutting the gneisses and schists in Animas Valley. One of these occurs at the lower end of the canyon, near Rockwood, and extends beneath the Cambrian quartzite. A gabbro mass in gneiss occurs just north of Ignacio Lakes, and is covered by the sediments on its western side.

The Needle Mountains quartzites and slates are not penetrated by any large granite masses, but the Eolus batholith appears to have come up along the southern fault border of the quartzites and sends some small arms into them. It is evident, moreover, that the granite must be later than the Needle Mountains sediments, because it bears no evidence of crushing or other metamorphism at the time of the complex folding and shear faulting to which the quartzites and slates were subject. The development of chiastolite in some of the slate bands may be plausibly attributed to the metamorphosing action of the granitic mass.

It would appear that the massive granites of the Needle Mountains may belong to the same epoch of intrusion as the Pikes Peak granite, which cuts the quartzites of the Front Range and includes many fragments of the same.

UNCOMPAHGRE CANYON.[a]

In the course of mapping the Silverton and Ouray quadrangles opportunity was given for the study of the section of quartzites and slates or shales referred to the Algonkian by Van Hise (1889) and Emmons (1890). This section extends for several miles along the Uncompahgre Canyon, being overlain by volcanic tuffs except near Ouray, where a fault brings the upturned lowest Paleozoic strata, there of Devonian age, against the quartzites. The structure of these beds is that of an elongated dome, the apex being near the southern end of the exposures in the Silverton quadrangle. Neither base nor top of the section is visible. Some 8,000 feet of alternating quartzites and minor slates are exposed, and the formation is seemingly identical with that forming the compressed synclinorium in the Needle Mountains.

RICO MOUNTAINS.[a]

At the heart of the Rico Mountains uplift, which is due partly to a quaquaversal fold and partly to laccolithic intrusions of porphyry, there are small faulted plugs of massive quartzite and of dense schist, which have been referred by Cross to the Uncompahgre formation.

LA PLATA MOUNTAINS.[a]

The metamorphic area represented by the Hayden map in the heart of the La Plata Mountains is of Paleozoic and Mesozoic sediments. There are no pre-Paleozoic rocks exposed there.

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[a] By Whitman Cross.

CORRELATION.[a]

The ancient granites, gneisses, and schists constituting the oldest basal rocks of the mountains (division 1 of Cross) are referred to the Archean. They are similar in lithology and complexity to the Laurentian rocks of Canada and the Lake Superior region, using the term in its restricted sense. (See p. 325.)

The metamorphosed basic volcanic rocks of the Salida district and of the Needle Mountains (division 2 of Cross) can not be satisfactorily classified. They are older than the Algonkian sediments and younger than the Archean granites and gneisses. Cross and Howe provisionally refer them to the early Algonkian. This correlation is here followed because they are doubtless much more recent than the plutonic granites and gneisses of the Archean, but their reference to the early Algonkian rather than the late Archean is largely one of personal choice. These outcrops are similar to the hornblende schist series at the base of the sedimentary series in the Grand Encampment district of Wyoming, described by Spencer, and to the volcanics of the southern Piedmont, described by Keith. In the latter district Keith has referred them provisionally to the Algonkian because of the extended interval which must have elapsed between their eruption and the formation of the plutonic igneous granites and gneisses upon which they rest. Similar rocks are known in both the Archean and the Algonkian of the Lake Superior region.

The pre-Cambrian sedimentary rocks (division 3 of Cross) and the massive igneous rocks intrusive into them (division 4 of Cross) are referred to the Algonkian. The latter may be in part post-Algonkian.

No attempt is made to classify the basal gneisses of the Georgetown quadrangle, believed by Spurr to be of sedimentary origin. The quartzites of the Needle Mountains may constitute a part of a great pre-Cambrian terrane formerly continuous with the quartzites of the Wasatch and Uinta mountains, the Grand Canyon, and the Belt series.

SECTION 7. WYOMING.

SUMMARY OF LITERATURE.

LARAMIE, MEDICINE BOW, AND PARK RANGES IN SOUTHERN WYOMING.

STANSBURY,[54] in 1853, states that in the Black Hills (Laramie) is an extensive formation of massive red feldspathic granite with occasional outcrops of ferruginous quartz.

HAYDEN,[107] in 1863, describes the Laramie Hills as consisting of numerous centers of uplifted granite upon the sides of which the Carboniferous limestones lie in unconformable patches. There is

[a] By the authors.

every gradation from unchanged fossiliferous limestone to completely metamorphosed rock, melted material sometimes being found thrust into the seams of the unchanged mass. The core of Laramie Peak is of granite, while around it, as if thrown off by this nucleus, is a series of Azoic stratified rocks consisting of gneiss, hornblendic, micaceous, and talcose slates, syenite, and quartz, which are cut here and there by dikes of trap or basalt.

HAYDEN,[61] in 1868, mentions granites and syenites as occurring in the Laramie and Medicine Bow ranges. On the east side of Laramie Range, especially near Fort Laramie, are seen the distinctly discordant relations between the crystalline rocks of the mountain range and the unmetamorphosed strata.

HAYDEN,[34] in 1872, describes, on one of the branches of the Chugwater, in the Laramie Mountains, as occurring interstratified with red feldspathic granite, beds of magnetic ore which resemble the Lake Superior iron ores. The rocks between the headwaters of the Chugwater and Laramie consist of beds of quartz, black gneiss, seams of feldspar, with now and then beds of massive granite. On approaching the mountains the red feldspathic granite is found in great ridges, the gneissic strata diminishing and the massive granite increasing in approaching the mountain range.

ENGELMANN,[108] in 1876, finds that the Laramie Peak system consists of the igneous rocks granite and granitic syenite. Among the igneous rocks are also greenstones, which are of later date than the granite, in which they frequently are dikes.

HAGUE,[35] in 1877, gives detailed descriptions of the Laramie, Medicine Bow, and Park ranges. The Archean rocks of the Laramie Hills are classed under granites, gneiss, mica schist, and hornblende schist, the first covering much the largest area. The central body consists of coarse-grained granite. Above this, and forming the outer edges, dipping east-west, away from the main mass, occur heavily bedded granitoid rocks. At the north and south ends of the range the granites gradually pass into well-defined gneisses and schists, there being the most gradual transitions from the massive granites to the thinly laminated schists. Among the crystalline rocks is a variety of gabbro in the region of Iron Mountain and Chugwater and Horse creeks, where it forms knobs and knolls protruding through the granitoid rocks. At Iron Mountain, north of Chugwater Creek, are masses of titaniferous iron ores incased in the granite. No large bodies of eruptive granites were seen, nor eruptive rocks younger than the Archean. In structure the Laramie Hills are regarded as a broad anticline, accompanied by many secondary folds. There is no case of decided unconformity in the entire series of beds, and their uniform character indicates that they all belong to one division of the Archean, which, without doubt, is the Laurentian. The sedimentary rocks of the eastern foothills everywhere rest unconformably upon the Archean crystallines. East of Table Mountain is the only outlying mass of Archean granite occurring eastward of the sedimentary foothills.

The second great range of the Rocky Mountains—the Medicine Bow—like the Laramie Range, is made up almost exclusively of Archean crystalline rocks. In their general habit they resemble the formation of the eastern range, but additional varieties are found. The rocks include granite, gneiss, hornblende schist, mica schist, dioritic schist, slate, argillite, quartzite, chert, hornstone, conglomerate, and limestone. The larger bodies of true granite are confined to the southern end of the range, where it is closely connected with the Front Range of Colorado. Even this granite shows more or less tendency to bedding, the constituent minerals being arranged in parallel layers. From Brush Creek northward 15 or 20 miles are light-colored mica gneisses and dark hornblende schists, with occasional beds of vitreous quartzite. Medicine Peak is a mass of pure white quartzite rising 2,000 feet above the surrounding country. The main ridge has a trend approximately N. 20° E., which appears to be the strike of the rocks. The dip is to the east at a high angle. While no accurate measurements could be made, the thickness of the formation is certainly not under 2,000 feet. The quartzite is white, compact, and brittle, with a uniform texture, and is traversed by thin iron seams. Near the base of the formation the quartzite is interstratified with beds of conglomerate, the pebbles being of quartz, and many of them having been pressed and elongated in the direction of the strata. The formation is cut by dikes of dark intrusive rocks which are probably diorites. At the head of the northern branches of French Creek, conformably under a quartzite, is a series of thinly laminated, dark argillaceous slates and schists, which dip eastward into the mountain. Below these are quartzose argillites, which are again underlain by crystalline schists. Mill Peak, north of east from Medicine Peak, has at its base a white quartzite, which is overlain by a body of red conglomerate resembling the red jasper conglomerate of the Huronian series of Lake Huron. Above this is amorphous quartzite, and the peak is capped by white and gray siliceous limestone. The prevailing dips at Mill Peak are to the west, while those at Medicine Peak are to the east, indicating that there is a broad synclinal fold between the two. A striking characteristic of the entire series is the banded and laminated appearance of the constituent minerals. The Archean series of the Medicine Bow Range present many marked features analogous to the Huronian formation on the shores of Lake Huron and in Canada, as well as to various localities throughout the Appalachian chain; and they are—with considerable hesitation, however—recognized as of Huronian age, because they are so widely separated from any beds distinctly recognized as such, and the reference is based entirely upon lithological evidence. The rocks also present many features in contrast with Laurentian rocks of the Colorado Front Range.

The Park Range, the third of the great Archean uplifts of the Rocky Mountains, is a system of highly crystalline rocks of Archean age. The later rocks form a very subordinate part of the uplift, rising not more than a few hundred feet above the plain, where they rest unconformably on the older series. The rocks of the Park Range resemble more closely those of the Colorado Front Range than they do the Medicine Bow, and are referred to the Laurentian. The range contains much structureless granite overlain by gneisses and schists similar to the series of the Colorado Range, but carrying more hornblende-bearing beds in the upper members. On the other hand, there are not wanting rocks which are characteristic of the Medicine Bow series and which were referred to the Huronian formation. The range has a monoclinal structure, with the prevailing dips to the west, while an outlying spur to the east indicates the existence of the eastern side of the fold.

EMMONS,[35] in 1877, describes Rawlings Peak as an outlying area of Archean granite gneiss which shows distinct lines of bedding, having an inclination of 45° W., while the overlying quartzites and sandstones dip 10° E.

KING,[36] in 1878, describes the rocks which unconformably overlie the Archean of the Colorado Range as varying from the lowest Paleozoic up to the post-Pliocene. The Archean core of the range is a broad central anticline, the arch having a flat summit and the dip increasing rapidly as the axis becomes distant. In this range complex faulting, metamorphism, and crystallization, combined with widespread erosion, took place before the beginning of Cambrian time. The rocks comprise granites and granite gneisses, above which, with no apparent unconformity, are red granites, showing distinct bedding, and above these is a great thickness of mica gneisses, estimated to be 12,000 to 18,000 feet. From the lowest exposure to the highest there is a gradual passing from the structureless granite to the dark mica gneisses. Among eruptive rocks are granites, gabbros, and felsite porphyries. The Clarks Peak ridge is thought to be another and later series of rocks than those of the Colorado Range.

In the Medicine Bow Range, above the hornblendic and dioritic gneisses and schists are quartzitic schists, argillites, and limestones. The gneisses and hornblende schist are older and underlie, in apparent conformity, the quartzites.

In the Park Range the crystalline rocks all dip to the west, being but half of an anticline, the other half having suffered a deep downthrow which has left only traces of the easterly dips. The rocks are granite, gneiss, hornblende schists, and dioritic rocks, with a limited quantity of quartzites, there being no eruptive rocks, unless some obscure dioritic bodies are intrusive. At Jacks Creek is a bed of pure white quartzite 50 feet thick. The upper members of the Medicine Bow and Park ranges, somewhat less than 12,000 or 14,000 feet thick, are referred to the Huronian and the remaining formations to the Laurentian.

Endlich,[109] in 1879, describes Rawlings Peak as consisting of a metamorphic granite nucleus about which the sedimentary strata are quaquaversally arranged.

Van Hise,[38] in 1889, made observations on the Laramie and Medicine Bow ranges.

The Laramie Hills at Sherman, where most structureless, are found to have alternate bands of coarse and fine material. The latter are more resistant to weathering and stand out as ridges. This stratification or flowage or foliation structure is at a flat angle—15° or 20°. The country granite is cut by very numerous dikes of granite, which project above the ground in intersecting ridges.

The course of travel in the Medicine Bow Range was up one of the branches of the Laramie River to Medicine Peak, and over this range in a course north of west, across the strike of the rocks, down Brush Creek. Mill Peak was visited.

The pre-Cambrian rocks first found are banded and contorted gneisses, varying from fine-grained to granitoid varieties, which are cut by hornblendic and granitic veins or dikes, with here and there considerable areas of massive granite. Toward the interior of the range the granite becomes less plentiful and the gneiss more laminated, passing into regularly banded gneiss, which appears to grade by imperceptible stages into fine-grained green schist, and finally into black slate. Farther west quartzites are found, then a broad belt of yellowish white, finely granular chert, with layers of cherty limestone sometimes ferruginous. About a mile before Medicine Peak is reached the quartzites appear. These continue (often conglomeratic) to beyond Medicine Peak. West of Medicine Peak are again found slates, slate conglomerates carrying abundant pebbles of white quartz, and granites, interstratified with quartzite. Schistose and massive basic rocks, much altered, in dikelike forms, are found in the clastic series precisely as in the gneissic series. In many places they strike approximately parallel to the inclosing rocks. East of Medicine Peak the rocks, including the gneissoid and clastic series, have a dip of about 60° to 80° SE.; therefore the Medicine Peak series appears to underlie the gneissoid series. North of west, beyond the mountain, the dip of the Medicine Peak series becomes flatter, until 2 or 3 miles beyond the crest the dips are not higher than 30°, which observations agree with Hague's statement that west of Medicine Peak is the crown of an anticline. As the strike of the Medicine Peak series is nearly toward Mill Peak, and as on the top of that peak there are cherts (Hague's amorphous quartzite) and cherty limestones very like those found east of Medicine Peak, it seems probable that the Mill Peak series represents these cherty limestones. Though the original sedimentary character of the Medicine Peak and Mill Peak series is evident, the pressure to which the rocks have been subjected is so great in places that the slate conglomerates bearing granite pebbles take on an appearance closely resembling gneisses. The grains of quartz in the fragmental quartzites in thin section also show profound evidence of dynamic action. However, as the layers of pebbles in the quartzites and the fine laminations in the cherts and cherty limestones correspond with the schistose structure, there can be no doubt that the strikes and dips are those of bedding.

The foregoing facts seem to imply that in going up from the gneissic series to west of Medicine Peak we have passed a syncline overturned to the west, and 2 or 3 miles west of Medicine Peak have nearly reached the crown of the next anticline. This structure makes the slates and slate conglomerates bearing granite pebbles the base of the clastic series, above which are the quartzites, and occupying the highest position in the center of the syncline are the cherts and cherty limestones of Mill Peak and those east of Medicine Peak. The clastics thus rest upon the granite gneiss series. No contacts or evidence of discordance in strike or dip were found between them, but the conglomerates bearing granitic detritus show the presence of a granite earlier than the formation of these beds, and presumably the present apparent accordance and transition are due to dynamic action, combined, perhaps, with the disintegration of the earlier series before the clastics were deposited.

Blackwelder,[110] in 1908, states that in the southern part of the Laramie uplift a complex sequence of pre-Cambrian igneous and other rocks has been worked out. The oldest rocks are schistose basic and acidic volcanics, with other metamorphic rocks of unknown origin, and a few which seem to be highly altered quartzites. Into the schists have been intruded two varieties of granite, both of which have been subsequently metamorphosed into gneisses. Into both the schistose and the gneissic series a variety of other igneous rocks have been intruded. They comprise diorites, gabbros, granite porphyries, and anorthosite. A few of these are slightly metamorphosed, but the majority are not schistose. All of the foregoing rocks occur in the form of irregular patches embedded in and surrounded by a vast intrusive mass of coarse-grained granite, believed to be the same as that which has a wide distribution southward in Colorado. No distinct series of sedimentary rocks is exposed in this district, and it is therefore not easy to refer any of the eruptives to one division or the other of the pre-Cambrian. On the ground of alteration or lithologic features, however, the oldest schistose rocks and the gneissic granites by which they are invaded may be tentatively referred to the Archean. The granites and other intrusives may well be of distinctly later age.

BIGHORN MOUNTAINS.

Hayden,[111] in 1861, states that red feldspathic granites, with metamorphic slates and schists, constitute the nucleus of the Bighorn Mountains. As these are surrounded by strata as recent as the Cretaceous, this uplift is subsequent to this time.

Hayden,[112] in 1868, states that the unconformity between the crystalline and unmetamorphosed strata at the Bighorn Mountains is very apparent.

Carpenter,[113] in 1878, describes the Bighorn Range as composed at the base of thick masses of Primordial sandstone resembling the Potsdam sandstone of the Black Hills, although the heat coeval with the upheaval of the mountains has probably obliterated the fossils which are so abundant in that region. The sandstone rests unconformably against the Archean, is inclined from the flanks, is folded, and in many places is upturned as in the Black Hills and Colorado Mountains. Above the sandstone is a limestone containing numerous casts of *Spirifer cameratus*. The crystalline rocks appear at an elevation of about 9,000 feet and compose the higher parts of the range. Near the summit fine-grained grayish granite predominates, occasionally varied by patches of mica schist. The Owl Creek Mountains are composed of porphyritic granite rich in feldspar, which gives place at higher elevations to a gneissoid granite. They connect the southern end of the Bighorn Mountains with the northern part of the Wind River Range.

Darton,[114] in 1906, describes the granite in the northern central portion of the Bighorn uplift as occupying an area of about 1,200 square miles. Its form is elliptical, extending about 62 miles north-northwest and south-southeast and having its greatest breadth, about 30 miles, near Cloud Peak. To the north and south, as well as on the sides, the granite passes beneath the sandstone at the base of the Deadwood (Cambrian) formation. To the northwest it reappears again in the center of the uplift in an irregular, narrow zone extending from the foot of Hunt Mountain past Bald Mountain nearly to the Montana line. A small exposure appears in the crest of the anticline in the middle of the range near Point Lookout in Montana and in the anticline of Dry Fork Ridge where it is crossed by the canyon of Little Horn River.

In the southern portion of the Bighorn Mountains the granites appear along a fault northeast of Bigtrails and in an area of about 100 square miles near the southern end of the mountains, due to local increase in the amount of uplift. The latter area is in an elevated region along the upper portions of Badwater, Clear, Lonetree, Lost, Deep, and Trout creeks and the west fork of Powder River.

In the Bridger uplift the pre-Cambrian rocks occupy an area of about 65 square miles, constituting the high central summits and the long, rugged southern slopes. They also are exposed by deep erosion in the upper canyon of Bighorn River at the west end of the Bridger Range.

RATTLESNAKE (BRIDGER) MOUNTAINS.

ENGELMANN,[108] in 1876, states that granites and granitic syenites which are regarded as igneous rocks form a large part of the Rattlesnake Mountains.

SWEETWATER AND ADJACENT MOUNTAINS.

BALL,[115] in 1835, notes granitic rocks along the Sweetwater.

HAYDEN,[112] in 1868, mentions granites and syenites as occurring in the Sweetwater Mountains.

ENGELMANN,[108] in 1876, places the crystalline schists between the three crossings of the Sweetwater and South Pass, and those on the eastern slope of South Pass, as metamorphics. They include gneiss, mica schist, argillaceous and siliceous schist, and hornblendic rocks.

ENDLICH,[109] in 1879, describes Prozoïc and metamorphic rocks in the Sweetwater Valley and adjacent regions. In the Sweetwater Hills are Prozoic rocks, coarse-grained, structureless granites, like those west of the Wind River Mountains, which are cut by basaltic dikes that never penetrate the overlying younger rocks. The metamorphic granite of the Sweetwater and Seminole hills is regarded as a continuation of the youngest granite of the eastern slope of the Wind River Range. East of Elkhorn Gap is found a series of folded sedimentary beds, upon both sides of which is granite apparently of the same character. The northern and northwestern portions of the granite hills, instead of being composed of Prozoic granite, are formed of stratified granites with hornblende schists. Toward the eastern termination the stratification is so apparent that from a short distance the rocks were supposed to be unchanged sedimentary ones, and the suspicion presented itself that a portion of these are metamorphosed Silurian beds. The Potsdam quartzite with an easterly dip is found to rest upon the schists, and at the western end of the Sweetwater hills sub-Carboniferous dolomites rest directly upon the Prozoic granites. In the Sweetwater region the younger metamorphics occupy a more conspicuous position than the older metalliferous schists. That the older schists and Prozoic granites do not appear is due to the thickness of the youngest metamorphic series, erosion not having succeeded in cutting through them. The metamorphics are all referred to the Huronian system.

WIND RIVER MOUNTAINS.

HAYDEN,[111] in 1861, states that the Wind River Mountains have a nucleus of red and gray feldspathic granite.

HAYDEN,[112] in 1868, states that the stratified rocks rest unconformably upon the granites and syenites of the Wind River Mountains along the eastern slope.

HAYDEN,[34] in 1872, describes the Wind River Range as forming a complete anticline. It has a nucleus of granitic or gneissic rocks rising on either side step by step toward the central axis, and on each side of the nucleus are the various unchanged rocks inclining at a variety of angles. From Fort Stambaugh northwest toward the granites of Wind River are found for a distance of 10 miles metamorphic slates.

COMSTOCK,[116] in 1875, describes the Wind River Mountains as having a nucleal area of gray and reddish granites, gneissoid granites, gneisses, metamorphic slates and schists, and pre-Potsdam metamorphics, this being the order of succession from the center to either flank. It is doubtful whether any igneous rocks occur here, and there appears to be a gradation from the structureless granites to the pre-Potsdam metamorphics.

ENDLICH,[109] in 1879, describes the geology of the Wind River Mountains and the country eastward. The crystalline rocks are divided into Prozoic and metamorphic. Placed as belonging to the Prozoic is the coarse-grained, structureless red granite forming the subsidiary range along the western base of the mountains. Eastward the granites disappear and in the Wind River Range schists take their place. These granites and those of the Sweetwater and Granite hills are believed to have a subterranean connection and are regarded as the oldest rocks of the Wind River Mountains because of the absence of all structure, their position relative to the range, and their relations to the undoubted metamorphics to the east. Against them were deposited the old metalliferous schists. Granite composing the main chain followed, and this was succeeded by a narrow band of schist, and the fourth or lowest group is represented by the younger granites. The metamorphic rocks of the Wind River Mountains are mainly granites but are associated with schists; but the layers of different mineralogical constitution do not appear to remain constant in certain zones. Eastward the granites disappear and are replaced by schistose granites or typical schists. The granites are flexed and contorted in every possible direction and contain simple bands of micaceous and chloritic schists, which denote the original planes of stratification. It is believed that by a careful examination evidence will be found bearing upon the former condition of this metamorphic area. The Wind River Range is regarded as a steep anticlinal fold. The rocks constituting it are regarded as representing siliceous shales (schists) and are more or less argillaceous sandstones (granites). On the eastern side of the Wind River Range is found hard, red, quartzitic sandstone directly overlying the youngest metamorphic granites. It extends up the gently sloping ridges in a scalloped line. In direct contact with the granites it is difficult to determine where the granite ends and the quartzite begins, so that it may be said that the quartzites and granites blend into each other. It appears that the lowest Silurian strata were deposited before the thorough metamorphism of the entire mass took place, unless the change in the sandstone was caused by generation of heat during the period of mountain elevation. The Archean rocks of the Wind River, Sweetwater, and adjacent ranges are classified into the Huronian, Laurentian, and Prozoic systems. The first includes micaceous, hornblendic, and chloritic granite, 30,000 feet thick. The Laurentian includes metalliferous schists composed of quartz, feldspar, hornblende, and mica, 18,000 feet thick. The Prozoic includes massive structureless muscovite granite of indefinite thickness.

Peale,[37] in 1879, states that the western foothills of the Wind River Mountains and a few isolated buttes are composed of muscovite granite, the most prominent of the latter being Fremonts Butte.

St. John,[117] in 1883, describes the Archean rocks of the Wind River Range and gives a number of sections showing the unconformable relations of these rocks to the overlying Potsdam and higher sedimentaries. The Archean area is composed of granitic, gneissic, and various schistose rocks, including hornblendic, micaceous, talcose, and garnetiferous varieties.

GROS VENTRE AND WYOMING RANGES.

St. John,[118] in 1879, states that the Gros Ventre Range has an Archean nucleus, consisting chiefly of distorted gneissic and schistose layers, and forms a sort of transverse bar or truss connecting the Wind River and Teton ranges. The Primordial quartzite was seen lying in immediate contact unconformably above the Archean schists, from which it is separated by a rose-colored, finely laminated gneissoid layer, which may be the metamorphosed basal member of the quartzite.

St. John,[117] in 1883, further describes the Gros Ventre Range and gives various sections through it. The Primordial quartzite rests directly upon the Archean rocks. In the Wyoming Range, as in the Gros Ventre Range, the Archean is unconformably below the stratified rocks.

TETON, ABSAROKA, SNOWY, AND GALLATIN RANGES SURROUNDING YELLOWSTONE PARK.[a]

Bradley,[47] in 1873, describes the central nucleus of the Teton Mountains as consisting of granites, gneisses, and schists, which vary greatly in character. No rock succession was ascertained. The granite is in thick solid beds and the other rocks are much broken and tilted in various ways, and are crossed in every direction by innumerable large and small veins, mostly of quartz, but a few of granite. There is a general strike in an east-west direction. Traplike rocks are interlaminated with the gneiss and granite, which suggests that they may be dikes, but they are evidently conformable with the layers and were either contemporaneous sheets or else subsequent intrusives.

St. John,[118] in 1879, describes Archean rocks as constituting the nucleal ridge of the Teton Mountains. The major portion of them are metamorphics of a gneissic or schistose variety. The Archean strata of the Teton, Wyoming, and Gros Ventre ranges are divided into Huronian and Laurentian. With the former are placed the quartzites and micaceous and chloritic slates, forming heavy deposits several thousand feet in thickness and developed only in the southwest, while with the Laurentian are the gneisses, various schistose rocks, and granite. In the southwestern part of the Teton district is a narrow tongue of quartzites which are placed with the Primordial, but may be Huronian.

Hague, Weed, and Iddings,[119] in 1896, map and describe the geology of the Yellowstone National Park, Wyoming. Archean rocks are found near the borders of the district, in the mountain ranges which encircle the park plateau. They comprise granites, gneisses, and schists. The granites and gneisses are for the most part coarsely crystalline, and the entire series shows the effect of metamorphism by pressure.

Algonkian rocks are recognized only in the southern end of the park, and are best exposed on the southern slope of Mount Sheridan, from which the formation has been called the Sheridan quartzite. The formation comprises sandstones and slates, which contain no fossils. Unconformably overlying the Sheridan quartzite is the Ellis (Juratrias) limestone. The assignment of the formation to the Algonkian is based largely on the fact that similar rocks are unknown in the Paleozoic series, and on the fact that no sedimentary rocks older than these quartzites are exposed in this district.

Hague,[120] in 1896, in a discussion of the age of the igneous rocks of the Yellowstone National Park, mentions the occurrence of rocks of Archean age in the surrounding mountain ranges. The Tetons, bordering the park to the south, consist mainly of an Archean mass,

[a] See also summary of literature of southwestern Montana and adjacent parts of Wyoming, under section 9, pp. 853–863.

which towers high above all later rock formations. In the Absaroka Range, stretching along the entire east side of the park and formed mainly of igneous rocks, granite and schists are exposed at the northern end. The Snowy Range, which shuts in the park to the north, is largely made up of Archean schists, gneisses, and granites, associated with the more recent outbursts of lava. In the Gallatin Range, on the west, a body of crumpled gneisses and schists forms the nucleus of the mass. The Archean masses formed either a part of a broad continental mass or a group of closely related islands. Resting unconformably upon the Archean are great thicknesses of Paleozoic and Mesozoic rocks.

HAGUE,[121] in 1899, describes the Archean rocks of the Absaroka quadrangle, in the northwestern part of Wyoming. These consist of crystalline schists and gneisses, mainly mica gneiss, amphibolites, and schists distinctly light colored, which are found only in the northeastern part of the Crandall quadrangle.

Sedimentary rocks of middle Cambrian age overlie the Archean rocks unconformably.

WYOMING, GENERAL.

NEWTON,[122] in 1880, describes the Rawhide Butte, a ridge consisting of a series of black micaceous schists or gneisses, with alternating strata of a coarse, very feldspathic granite dipping 70° to 75° E., with a strike N. 40° W. On the extreme southeast corner of the butte is a bed of graphic granite similar to that found in many places in the Harney Peak region of the Black Hills.

ELDRIDGE,[123] in 1894, from a geological reconnaissance in northwest Wyoming, finds that Archean granites, gneisses, and schists of various types form the crest of the Bighorn, Wind River, Absaroka, and Owl-Rattlesnake ranges. In the Wind River and Absaroka ranges the Archean areas are extensive. Resting upon the Archean rocks and in many places deriving material from them are the rocks of the Cambrian system.

KNIGHT,[124] in 1900, in connection with the discussion of the artesian basins of Wyoming, gives a brief description, accompanied by a map, of the geology of the State. Algonkian and Archean rocks are present. The Archean rocks consist mainly of granite, in places cut by dikes of porphyry containing mineral ores, which can be seen in typical exposure at Sherman, Laramie Peak, east of Whalen Canyon, along the Bighorn, Wind River, Gros Ventre, Medicine Bow, Ferris, Seminoe, and Owl Creek ranges, along the Sweetwater River, a few miles northwest of Rawlings, and north of Clarks Fork, in Bighorn County.

The Algonkian rocks are for the first time separated from the Archean. They consist of schists in great profusion, marbles, and quartzites, all cut by dikes of eruptive rocks. They occur in granite basins in unconformity with the Archean, and form important bands in numerous localities. The strike of the series varies from north to northeast, and the dip of the strata is seldom less than 65° to 75°. The thickness of the entire series has not been absolutely measured, but including the eruptive band, which does not form an important part, the maximum thickness in Wyoming is about 20,000 feet. Typical areas have been found in the Black Hills in Wyoming, and occasional outcrops from that place to the Hartville Hills—one exposure being east of Lusk, another at Rawhide Butte, and a large one in Whalen Canyon. Algonkian rocks also occur at Halleck Canyon, Plumbago Canyon, in the Medicine Bow Mountains, nearly all of the Sierra Madre, in the Seminoe Mountains, and in the Sweetwater mining district of the Wind River Range. None of these localities have been examined in detail, but it is thought that these rocks were at one time sedimentary and that they have been changed by metamorphism to schists. In the Sweetwater district the rocks are chiefly schists, but there are many dikes of eruptive rock which follow the strike of the formation.

Smith (W. S. Tangier),[125] in 1903, describes the geology of the Hartville quadrangle, in Wyoming. The Whalen group, assigned to the Algonkian, consists of gneisses, schists, quartzites, and limestones, all very schistose, the schistosity standing nearly vertical. These rocks occur principally in the northeastern part of the quadrangle. Quartzites and micaceous schists form the greater part of the exposed rocks of the Whalen group, and in places they grade into each other, so that no definite separation can be made. Some of the quartzites are more or less calcareous. Iron ore occurs within and near the contact of the limestones and schists of the Whalen group on the west side of Whalen Canyon. Information at hand is not sufficient for a determination whether there are several ore-bearing horizons or a single horizon repeated by folding. Ore is being mined at Sunrise.

Spencer,[126] in 1904, discusses the geology of the Encampment district of Wyoming. Pre-Cambrian rocks form the main mass of the Sierra Madre, with Mesozoic beds dipping away from them. They comprise sedimentary and igneous rocks. The sedimentary rocks are, from the base up: Hornblende schists, derived from surface volcanic rocks, interbedded with thin but persistent beds of sandy shale and impure limestone, limestone, quartzite, slate, and conglomerate. In the Encampment area the quartzite and slate formation is more in evidence than any other of the bedded rocks, but all occur in a limited area having the form of a narrow triangle, with its apex on the Encampment River about 5 miles south of Encampment, and its base, about 7 miles wide, in the foothills on the west side of the range. The belt of quartzites and associated strata is exposed for about 20 miles, but on the west their extent is not known, since they are overlapped by younger formations. The rocks within the sedimentary belt strike in general nearly east-west, and they seem at first sight to have an enormous thickness, since they dip almost invariably toward the south. An examination shows the sediments to be in an east-west synclinorium, with axial planes of both major and minor folds dipping to the south. Strike faults and transverse faults are common.

A complex of igneous rocks comprising granite, quartz, diorite, and gabbro is found both north and south of the synclinorium, and the gabbro occurs also within the synclinorium. The relations of the granite and quartz diorite to the sediments are not definitely known, but their distribution is such as to suggest that they are intrusive into the hornblende schists at the base of the sedimentary series, and that with the hornblende schists they form the basement upon which the sedimentary rocks were deposited. The gabbro is intrusive into the sediments.

Darton,[127] in 1905, describes and maps the geology of the Sundance quadrangle, in Wyoming and South Dakota. Mica schists, believed to be of sedimentary origin, assigned to the Algonkian, similar in most respects to those which outcrop in the central part of the Black Hills, appear in several irregular areas in the Nigger Hill uplift. A portion of them appear to be in place, upturned in the center of the uplift, but other portions are included in the younger igneous rocks which apparently completely surround them. These schists are penetrated by intrusive rocks of various kinds, including granites, amphibolites of Algonkian age, and other rocks. In the Bear Lodge uplift large masses of probable Algonkian granites are inclosed in the trachytes.

Smith (W. S. Tangier),[128] in 1905, describes Algonkian granite found on the Bear Lodge Mountains in the southwestern portion of the Aladdin quadrangle, mapped by Darton and O'Harra. The granites occur as large fragments in later igneous rocks.

Darton,[77] in 1905, in connection with a discussion of the artesian wells of the central Great Plains, maps and describes the pre-Cambrian rocks of eastern Wyoming. This is an excellent summary of the present state of knowledge of these rocks, especially in regard to distribution.

Darton,[129] in 1906, maps and describes the geology of the Bighorn Mountains, lying principally in the Bald Mountain, Dayton, Cloud Peak, and Fort McKinney quadrangles, in Wyoming. Pre-Cambrian granite forms the core of the mountains. The granite outcrops in the west-central and southern parts of the Dayton quadrangle, in isolated areas in the Bald Mountain quadrangle, in the eastern part of the Cloud Peak quadrangle, in the western part of the Fort McKinney quadrangle, and in isolated areas at both the north and south ends of the area treated, those in the southwestern part forming the core of the Bridger Range. It consists of gray and red granite, mostly massive, cut by basic dikes. Middle Cambrian rocks rest unconformably upon the granite.

Ball,[130] in 1907, describes the geology of the Hartville district of Wyoming. Steeply dipping pre-Cambrian rocks are unconformably overlain by flat-lying or gently dipping Carboniferous and Mesozoic rocks. The oldest rocks are an interbedded series of siliceous dolomitic limestones and muscovitic and biotitic schists of sedimentary origin. Interbedded with these are some quartzose beds and jaspers, while a second series of similar beds appears, on general structural grounds, to lie unconformably on the interbedded limestones and schists. The next youngest formation consists of diorites and gabbros and porphyries of similar chemical composition, which in instances are mashed into chlorite and hornblende schist and into hornblende gneiss. An intrusion of granite (similar to Black Hills granite) followed, accompanied by aplite and pegmatite dikes. The pink or gray coarse-grained granite is sometimes massive and again is gneissic. Younger than the granite are dikes of diabase, a greenish gray rock with small feldspar phenocrysts.

Prior to the deposition of the Carboniferous series the pre-Cambrian rocks were folded into a great syncline opening out to the east. The resultant mountains and valleys were then worn down to a level surface or plain by streams and the weather, and on the sharply upturned pre-Cambrian rocks the Carboniferous and Mesozoic rocks were deposited.

Ball,[130] in 1907, describes the pre-Cambrian complex near the large dike of iron ore at Iron Mountain, in the east central part of Albany County, Wyo., as consisting of three granular igneous rocks—an anorthosite, the iron ore, and a granite. The anorthosite is the oldest of these and is cut by dikes and lenticular masses of iron ore and granite. The relative age of the iron ore and granite was not certainly determined, since the exposures are poor where the two rocks are close to each other. All evidence, however, points to the iron ore being the older.

SUMMARY OF PRESENT KNOWLEDGE.

Granitic and gneissic rocks of pre-Cambrian age form the core of the Cordilleran range, running southeast-northwest through Wyoming, including the Park or Sierra Madre Mountains and the Medicine Bow, Laramie, Sweetwater, Wind River, Wyoming, Bridger, Gros Ventre, Teton, Absaroka, and Bighorn ranges.

Some of the granites and gneisses constitute the base upon which the pre-Cambrian sedimentary rocks lie, and should be assigned to the Archean. Such older gneisses have been discriminated from later intrusives only in limited areas.

Pre-Cambrian sedimentary rocks, including quartzite, conglomerate, slate, marble, schist, and gneiss, cut by a variety of intrusives, occur in occasional outcrops between the Black Hills of South Dakota and the Hartville district, on both sides of the Laramie Mountains, in the Hartville district, in Medicine Bow Mountains, in the Sierra Madre or Park Mountains, in the Seminoe Mountains, in the Sweetwater mining district of the Wind River Range, and on Mount Sheridan in the southern part of Yellowstone Park. They are mapped in most detail in the Hartville and Grand Encampment areas. (See Ball's and Spencer's accounts.)

The reference of these rocks to the pre-Cambrian is based on the fact that, except in a few localities where there is known to be overlap, they are overlain by deposits of middle Cambrian age, with an intervening unconformity that indicates a very long period of time.

The hornblende schists derived from surface volcanics in the Encampment district are also provisionally referred to the Algonkian. They are believed by Spencer to be the basement upon which the sedimentary rocks of this district were deposited, but they are so correlated because of their similarity to the Irving greenstone of Colorado, which has been provisionally called Algonkian. They are similar also to greenstones and green schists in both the Archean and the Algonkian of the Lake Superior region.

The difficulty of determining the relations of the granites and gneisses to the pre-Cambrian sediments is illustrated by Van Hise's description of contacts in the Medicine Bow Mountains. The Algonkian clastics of Medicine and Mill peaks of the Medicine Bow Mountains consist of slates and slate conglomerates bearing granite pebbles, above which are thick layers of quartzite, and above these are cherts and cherty limestones. These rocks appear to be in isoclinal folds overturned toward the west. The conglomerates are much mashed and the quartzites approach quartz schists. On the east side of the mountain one finds, in passing from the Archean toward the Algonkian, that the granite becomes less plentiful and the gneiss more laminated, grading into banded gneiss, which appears to change by imperceptible stages into fine-grained green schist, and finally into black slate. On the west side, at the base of the sedimentary series, are found the slate conglomerates which bear granite pebbles. It is believed that the facts are best explained by regarding the Algonkian clastic rocks of the Medicine Bow Range as unconformable upon the Archean. The apparent gradations are on the east side of a fold with an eastward-dipping axial plane. Therefore the junction between the two series is here a horizon of great slipping, and one where the sedimentary rocks were rendered crystalline. A parallel schistose structure was produced both in the sedimentary rocks and in the Archean. On the west side, however, where the shearing was less intense, the clastic character of the series is still discoverable.

If the above interpretation is correct the Medicine Bow Range affords another locality in which there is apparently complete gradation between a sedimentary and a crystalline series. If the facts of the gradation were taken by themselves they would be explained by some geologists as proof of the intrusive character of the gneissoid granite in the Algonkian; by others they would be taken as evidence of the progressive metamorphism of the Algonkian rocks into the Archean. But it has been seen that the more probable explanation is that the two are really unconformable, but have been mashed and metamorphosed until there is gradation between the two and conformity of secondary structures.

In the Bighorn Mountains the pre-Cambrian rocks are granites, and as no pre-Cambrian fragmental rocks appear, it has not been possible to ascertain whether the granites are Archean or Algonkian.

SECTION 8. IDAHO.[a]

SUMMARY OF LITERATURE.

ELDRIDGE,[131] in 1895, gives an account of a geological reconnaissance across Idaho, on a northeast line through Boise and Salmon City. Rocks are found which are provisionally referred to the Archean and Algonkian. To the Archean are referred granite and gneiss, which have their greatest development in the mountains of the western part of the State, but which are also widely exposed elsewhere. In places in the granite and gneiss are included bands of calcareo-micaceous or quartzitic slates, and in these cases the reference of the rocks to the Archean, instead of the Algonkian, is questionable. To the Algonkian is provisionally assigned the great series of micaceous, quartzitic, and chloritic schists of eastern Idaho. The reference is based merely upon lithological character and the resemblance to other beds in the Cordilleras which have already been so assigned. The Algonkian series in areas of strong development has a probable thickness of 3,000 to 4,000 feet. It is believed to be unconformable with the underlying granite.

RANSOME,[132] in 1901, in the course of a reconnaissance from Kootenai River westward along the international boundary, found that the prevailing rock along the Kootenai from Bonners Ferry northward to Porthill is a coarse, porphyritic, granitic gneiss. This

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[a] See also summary of literature on southwestern Montana and adjacent parts of Idaho, section 9, pp. 853–863.

is apparently overlain to the east by more than 20,000 feet of sedimentary rocks described by Daly[a] and probably in part the equivalent of the Algonkian sediments of the Cœur d'Alene district.[b]

The granitoid gneiss forms a belt at least 10 miles wide along the international boundary, and seems to be continuous with a broad band of gneiss and granite stretching from Bonners Ferry on the east to Priest Lake on the west and extending southward past Pend Oreille and Cœur d'Alene lakes. Some crystalline schist is associated with the gneiss along Boundary Creek, west of Porthill, the gneiss being intrusive into the schist. Near the head of Priest River, in the extreme northwest corner of the State, crystalline schists predominate over the gneiss. They include mica schist, quartz schist, limestone schist, and schistose conglomerates, with some massive quartzite.

No fossils have been found in these metamorphosed sediments. Their reference to the Algonkian depends upon the fact that they belong to a crystalline complex that as a whole underlies the unmetamorphosed sediments east of the Kootenai River, the latter being probably pre-Cambrian.

Lindgren,[133] in 1904, made a geological reconnaissance across the Bitterroot Range and Clearwater Mountains, in Montana and Idaho. Practically the entire area of the Bitterroot and Clearwater mountains is occupied by granite with some gneiss. West of the Clearwater River, and only imperfectly exposed below the lava, is an extensive sedimentary area adjoining this granite; smaller sedimentary areas are exposed on Lolo Fork and on the head of the South Fork of Bitterroot River. In no place have well-defined fossils been found, but there is some foundation for the belief that the two last-named areas on the east side are very old, possibly pre-Cambrian, while the western area probably includes Triassic, Carboniferous, and possibly still older sediments. The granite constitutes a great batholith whose age is not certain, but probably post-Triassic. The gneisses include older gneisses of the Clearwater Mountains, probably of pre-Cambrian age, and later gneisses resulting from the deformation of the granite occurring principally on the eastern side of the Bitterroot Mountains. On the accompanying map all are colored together as pre-Tertiary.

Ransome,[134] in 1905, describes the geology of the Cœur d'Alene district of Idaho. The prevailing rocks are Algonkian sediments, at least 10,000 feet thick, consisting of arenaceous and argillaceous materials. No fossils have been found in them. Neither the stratigraphic base nor top in this district or in the surrounding region has

[a] Daly, R. A., Secondary origin of certain granites: Am. Jour. Sci., 4th ser., vol. 20, 1905, pp. 186–187.

[b] Ransome, F. L., Ore deposits of the Cœur d'Alene district, Idaho: Bull. U. S. Geol. Survey No. 260, 1905, pp. 277–282.

been found. On the west these sediments extend to Cœur d'Alene Lake, where they are probably faulted down against the granitic and gneissic rocks forming the western shore of that picturesque body of water. On the north practically nothing is known of the extent of these Algonkian rocks. It is not unlikely that they continue northward past Pend Oreille Lake and are connected with the great series of Algonkian beds known to occur in the northwest corner of Montana. On the east, beds of the same character as those occurring in the Cœur d'Alene district extend to Missoula River at the mouth of the St. Regis de Borgia. Here there is apparently some change in lithological character, but quartzites and red and green siliceous argillites, probably of Algonkian age, extend at least to the town of Missoula, in Montana, and probably for some distance farther east. The area of Algonkian sediments has a width of about 80 miles between Cœur d'Alene Lake and Missoula River, and it is probable that extensive exposures of Algonkian beds continue 100 or more miles to the eastward, connecting the Cœur d'Alene area with the known Algonkian areas of central and northern Montana.

On the south Lindgren[a] has shown that the sedimentary rocks near Lolo Pass, which are probably part of the same series that prevails in the Cœur d'Alene Mountains, are cut off by the great granitic batholith of central Idaho.

Lindgren,[135] in 1905, states that identified pre-Cambrian rocks are absent in central Idaho and eastern Oregon. There are, however, several smaller areas of coarse gneisses inclosed in much later and probably late Mesozoic granites and quartz monzonites, which occupy so much space in these States. These areas are rarely directly connected with distinct sediments. It is believed that they represent part of an old Archean basement. One of these areas, about 10 miles square, occurs some 20 miles northwest of Sumpter, Oreg. Another similar mass occurs 90 miles southeast of Lewiston, Idaho. This is about 30 miles long and 20 miles wide. Other gneissoid masses are inclosed in granite on the Nez Perce trail near the boundary of Idaho and Montana. One of these areas connects with a mass of sediments of unknown, possibly pre-Cambrian, age. These same sediments appear in patches along the Bitterroot Range, and are finally developed on a great scale in northern Idaho between Lolo Fork and the Northern Pacific Railway. No fossils have ever been found in them and they are suspected to be of the same age as the Belt series of central Montana.

Collier,[136] in 1906, in discussing the ore deposits in the St. Joe River basin, Idaho, states that the Algonkian sedimentary series of

[a] Lindgren, Waldemar, A geological reconnaissance across the Bitterroot Range and Clearwater Mountains in Montana and Idaho: Prof. Paper U. S. Geol. Survey No. 27, 1904, p. 16.

the Cœur d'Alene district (the Belt series) extends south through the St. Joe River basin with all the formations which have been distinguished in the Cœur d'Alene district. The rocks are intensely folded, and intruded by granite and diabase.

Calkins,[137] in 1906, extends the observations on the Algonkian rocks of the Cœur d'Alene district by a reconnaissance northward through the Cœur d'Alene, Cabinet, and Loop mountains to the international boundary, and eastward to the vicinity of Ravalli and Lothrop, in western Montana. In both directions a sequence generally similar to that in the Cœur d'Alene district (see pp. 850–851) persists, but in the eastern part of the zone rocks stratigraphically higher occur, whose succession was not satisfactorily worked out. These later rocks include some limestones, probably Paleozoic. The sequence found by Walcott (p. 862) in northwestern Montana is almost duplicated in this region, though with variations in detail, but a great thickness of rocks stratigraphically beneath Walcott's section is found.

The western boundary of the great zone of comparatively unaltered sediments coincides roughly in northern Idaho with a topographic depression extending from the southern end of Lake Cœur d'Alene northward across the international boundary at Porthill. West of this valley are hills carved from granites, gneisses, and schists. The schists and some of the gneisses are in all probability Archean. The granites are partly intrusive in the Algonkian as well as the Archean rocks. The actual contact of Algonkian and Archean rocks was not observed, being covered by basalt and alluvial deposits, but there are reasons for believing it to be, at least in part, a fault contact.

Ransome and Calkins,[137a] in 1908, discuss the geology of the Cœur d'Alene district of Idaho and of the adjacent territory. They cover no essential features not already covered by the preceding reviews by Ransome and Calkins (Nos. 134 and 137). However, instead of regarding the ancient schists and gneisses west of the Purcell trench as probably Archean, they state: "It is by no means certain that the rocks immediately west of the zone are Archean or that they are a part of the ancient floor upon which the Belt sediments were laid down."

SUMMARY OF PRESENT KNOWLEDGE.

The work of Lindgren, Ransome, and Calkins, summarized in the immediately preceding pages, gives the present state of knowledge so clearly that further summary is not necessary. A striking feature of recent developments has been the wide extension of the known area of the Belt sediments. Eldridge's account is vitiated by his assumption of an Archean age for the great Mesozoic batholith of central Idaho.

SECTION 9. MONTANA.

SUMMARY OF LITERATURE.

HAYDEN,[111] in 1861, describes, along the Madison, one of the forks of the Missouri, beds of feldspathic rocks and mica slates and clay slates above the eruptive granites of the region.

HAYDEN,[43] in 1872, describes Archean rocks at many points in southwestern Montana. Among the localities mentioned the following are worthy of note: On Black-Tailed Deer Creek, in southwestern Montana, is an immense thickness of alternating beds of quartzites, true gneiss, and mica schist, the first predominating, and inclining to the west from 30° to 45°. Old granite ridges are also found. On the north side of this creek are gneissic beds, which incline to the northwest at angles varying from 30° to 60°. On the Stinking Water are immense thicknesses of micaceous gneiss underlying massive layers of quartzite. Along Madison Canyon is found granite. The rocks adjacent to Virginia City are clearly stratified, wholly metamorphic, and are regarded as below the Paleozoic. On the Upper Gallatin are granitic nuclei, with the unchanged sedimentary beds upon the sides and summits inclining at various angles. In the first canyon of the Yellowstone are true gneissoid granite and micaceous gneiss of different shades of color, giving its sides a peculiarly stratified appearance. At Cinnabar Mountain is a plainly metamorphic, reddish, feldspathic quartzite, upon which rests unconformably the Carboniferous limestone. Hell-Roaring Mountain consists of stratified gneiss and massive red or gray feldspathic granite. At Horse Plain Valley are quartzites and micaceous schists, which rise beneath the limestones and quartzites of Carboniferous age.

PEALE,[138] in 1872, gives many details with reference to the lithological and mineralogical character of the rocks, the locations of which are given by Hayden.

HAYDEN,[45] in 1873, gives many additional facts with reference to the occurrence of Archean rocks in southwestern Montana and adjacent regions. The mountain range east of the Yellowstone, supposed to be mostly of igneous origin, has the characteristic granitic nucleus common to the mountain ranges of the region. In ascending the lower canyon of the Yellowstone the first ridge is composed mostly of metamorphic quartzite, the second of mica schists and granitoid gneiss. The ribboning and banding of the gneiss is quite remarkable for its perfection and regularity. Granitic rocks constitute the nucleus of the Yellowstone Range and make up a rugged granite range east of Clarks Fork. At Henry Lake and Tahgee Pass the quartzites and gneissic rocks appear beneath the limestones. The lower portion of the unchanged rocks are pebbly arenaceous sandstones and limestones containing pebbles which are much worn and are either quartz or micaceous gneiss, showing that the sediments were derived directly from the metamorphic rocks. The lowest strata of unchanged rocks are here regarded as Silurian, and probably Potsdam, although no organic remains were found. The Carboniferous limestones higher up are filled with characteristic fossils. In the Middle Canyon of the Madison the stratified rocks are also believed to belong to the Potsdam epoch, although no fossils were found lower than the Carboniferous, and here the unconformable relations of the limestones to the metamorphic rocks are clearly shown. On both sides of the Madison there is, in restricted localities, an enormous development of very hard, gray quartzitic sandstone, apparently partially metamorphosed, which evidently forms the underlying rocks of the sedimentary strata resting on the strictly metamorphic gneiss. No organic life has been found, yet it undoubtedly belongs to the oldest Silurian. Along the valley of the Madison, below the mouth of Cherry Creek, for several miles there are successions of gneissic beds, thousands of feet in thickness, which show great variety of composition and flexures in the bedding. In this gneiss are layers of black hornblende gneiss, 4 to 6 feet thick, which appear as though they were intrusions of trap. Near Helena the sedimentary beds overlying the granite are tilted from 20° to 45° past vertical. The work of reducing the metamorphic strata which underlie the entire country to a system and connecting them over extended areas has not been attempted, and it seems to the author an almost hopeless as well as a fruitless task.

Peale,[46] in 1873, describes at many localities crystalline rocks in southwestern Montana and adjacent regions. Gneissic and granitic rocks are mentioned in the Cinnabar Mountains, in the rocks of the Third Canyon of the Yellowstone, at Elk Creek, at the junction of the two forks of the Yellowstone, at West Gallatin Canyon, Bozeman Creek, and other localities. On one of the headwaters of the Madison are found quartz schists and chlorite schists, below which, in apparent conformity, are layers of limestone. Still below these are Carboniferous limestones. The whole is believed to be an overturn. Between Red Rock Lake and Henry Lake is an exposure of quartz schist dipping to the southwest at an agle of 20°, estimated to be 2,000 feet in thickness, which is believed to rest directly upon the granite. On Cherry Creek the gneissic rocks are succeeded by beds of massive quartzite, shale, limestones, etc., resting unconformably upon them, the latter being probably Lower Silurian.

Hayden,[139] in 1876, describes some geological sections about the headwaters of Missouri and Yellowstone rivers. There is an anticlinal axis between the Madison and the Jefferson which has a granitic nucleus, and on the east side of the Gallatin the Silurian rocks rest upon granitic hills.

HOLMES,[140] in 1883, describes the Silurian strata as resting upon the metamorphic rocks at Cinnabar Mountains. The butte at Bear Gulch is composed of vertical shales, and these are underlain by metamorphic quartzites. Between the butte and Junction Valley are hard metamorphic quartzites and quartzitic schists, which not improbably consist chiefly of altered and distorted Paleozoic or Mesozoic strata, though there is but slight resemblance to these formations. The ridge near the canyon of Bear Creek is composed of schists that have a decided quartzitic character. The East Gallatin Range is largely of granite. At different places the Archean granites are unconformably overlain by the Silurian.

DAVIS,[141] in 1886, describes Archean rocks as occurring in the neighborhood of Neihart, about the headwaters of Belt Creek, in the Little Belt Mountains. They are dark reddish and gray gneisses, with the folia generally at steep angles, cut by granitic eruptions that were not found to extend into the overlying bedded rocks. The Paleozoic series begins with a vast series of Lower Cambrian barren slates, at least 10,000 or 15,000 feet thick at many places. The slates are capped by hard sandstone or quartzite, 100 or 150 feet thick, persistent throughout the area examined, which is overlain by an equally persistent trilobitic limestone, 100 to 300 feet thick, clearly of Potsdam date. With the upper members of these slates are found diabasic eruptions. These Lower Cambrian slates are found in the main range at Cadottes Pass, in the Big Belt Mountains, and in the Little Belt Range. In the sections the Archean rocks at Little Belt are represented as resting unconformably below the Lower Cambrian slates, while on the Bridger Range they are placed in conformity with the slates.

PEALE,[142] in 1893 and 1896, maps and describes the geology of the Three Forks quadrangle in Montana. Archean gneisses and Algonkian sediments occupy large areas. The Archean gneisses occur principally in the foothills of the Bridger Range, the mountain masses at the northern and southern ends of the Madison Range, west of the Madison Valley and north of Virginia City, the southern part of the Jefferson Range, the foothills of the Gallatin Range, south of the Gallatin Valley, and beneath the Bozeman lake beds at the southern end of the plateau, between the Gallatin and Madison valleys. The rocks referred to the Archean may possibly include some that eventually may be referred to the Algonkian. The contacts of the Archean with the overlying sedimentaries are, in all cases, unconformable.

The Algonkian series comprises two divisions—the Cherry Creek beds and the Belt formation.

The Cherry Creek beds occupy an area of 30 to 40 square miles in the foothills immediately west of Madison River and a few miles north of the southern boundary of the quadrangle, and also a small area on the east side of the Madison Valley, at the western edge of the Madison Range. The rocks are marbles and interlaminated mica schists, quartzites, and gneisses. Between Cherry Creek and Wigwam Creek, on the west side of the Madison Valley, Cambrian strata rest unconformably upon the upturned edges of the Cherry Creek beds. Before the deposition of the Belt formation the Cherry Creek beds suffered extensive deformation.

The Belt formation occurs in the northern portion of the district—in the foothills of the northern portion of the Bridger Range, in the hills north of Gallatin and East Gallatin rivers, and in the rugged hills of Jefferson Canyon. In the lower portion of the formation are coarse sandstones and conglomerates, in the central part appear argillites and siliceous limestones, and in the upper part sandstones predominate. The Belt formation is overlain by the Flathead (Cambrian) quartzite. It is possible that further investigation may result in the reference of this formation to the lower part of the Cambrian. At present, however, it is referred provisionally to the Algonkian.

The Flathead and Gallatin formations (Cambrian) rest with marked unconformity upon the Archean for three-fourths of the district; for the remainder of the district they rest upon the Algonkian, and the unconformity, if it exists, is very slight.

Iddings, Weed, and Hague,[143] in 1894, describe and map the geology of the Livingston quadrangle, Montana. Archean crystalline rocks constitute a part of the southern half of the region. These include mica schists, phyllite, gneiss, and granite. Much of the granite is eruptive and carries angular blocks of other rocks. The foregoing are cut by veins and dikes of crystalline rocks, both basic and acidic. Resting unconformably upon the Archean rocks is the Belt formation, which is supposed to belong to the Algonkian period. This formation is found on the western flank of the Bridger Range. The rocks comprise sandstones, conglomerates, slates, and arenaceous limestones. The series is about 2,500 feet thick within the area mapped. The Algonkian rocks are overlain conformably by the Cambrian Flathead quartzite.

Weed and Pirsson,[144] in 1896, map and describe the geology of the Castle Mountain mining district of Montana. The Belt group of rocks, assigned to the Algonkian, occupies large areas in the district. The series presents no definite lithological horizons, but there is a general sequence, from the base upward, as follows:

Alternating shales and sandy beds.
Dark-gray, laminated, thinly bedded limestone.
Pearl-gray sericitic shales.
Sandy shales with thin beds of ripple-marked sandstone.
Red shales and slates.

The series has thus far yielded no fossils. It attains a thickness of 8,000 feet. Basic and acidic intrusive rocks penetrate the Belt formation very freely.

At many localities the Belt series is seen to be in conformable relations to overlying fossiliferous rocks of Cambrian age, the Flathead and Gallatin formations, and, while assigned to the Algonkian, the series is spoken of as forming the lower part of the Paleozoic of the area.

Weed and Pirsson,[145] in 1896, briefly describe and sketch the geology of the Little Rocky Mountains of central Montana. The core of the mountains is formed of crystalline schists, of which the type usually seen is a black glistening amphibole schist, or amphibolite. In the saddle west of Shellrock Mountain the series consists of amphibole schists and mica schists, pink gneiss, and white quartzites, the various rocks occurring in rapidly alternating beds but a few feet thick.

The crystalline schists are overlain by Cambrian sedimentaries. Intruded between the schists and sedimentaries is a great laccolithic body of granite porphyry.

The presence of the quartzite is taken as indicating the Algonkian age of the crystalline series. However, similar schists occurring in Montana have been generally classed as Archean, and these rocks are metamorphosed and quite unlike the slightly altered Belt Mountain Algonkian series. The crystallines are, therefore, not definitely assigned to either the Archean or the Algonkian.

Griswold,[146] in 1898, describes the geology of Helena, Mont., and vicinity.

Middle Cambrian, or Flathead, quartzite forms an important part of the ridge stretching from Helena southeast to Montana City, and northwest, west, and south around Mount Helena. The sedimentary rocks underlying most of the area of the city, on the north side of this Cambrian quartzite, are classed as Algonkian. The Algonkian rocks vary from clay slates to micaceous, sandy, or calcareous slates, which often become quartzites or limestones. The Algonkian slates seem to conform to the overlying strata in the dip of their beds. As there are many small folds, it is difficult to determine the thickness; 5,000 feet does not seem too large a total.

Walcott, in 1899, discusses the Belt terrane of Montana. See summary in Chapter II, pages 98–99.

Weed,[147] in 1899, maps and describes the pre-Cambrian rocks in the Fort Benton and Little Belt Mountains quadrangles, in Montana.

The Archean rocks are found only in the Little Belt Range, in the southwestern part of the Fort Benton quadrangle and the northwestern part of the Little Belt Mountains quadrangle. They are gneisses and schists of various kinds and of somewhat uncertain origin. They are, in part at least, of igneous origin, and none of them show any traces of sedimentary origin. Their relations to the Algonkian rocks are those of unconformity. The Algonkian rocks are found in the mountain tracts of the Little Belt Range, in Castle Mountain, and in the low range crossed by Sixteenmile Creek in the southwest corner of the Little Belt Mountains quadrangle. They are divided into the Neihart quartzite and the Belt formation,[a] both of which are parts of what Walcott has called the Belt terrane.

The Neihart quartzite is a hard pink and gray quartzite forming the base of the Belt terrane for this area. It is found in the vicinity of Neihart, in the Little Belt Mountains. Its thickness is about 600 feet. The Belt formation consists mainly of slaty siliceous shales, but also contains interbedded limestone and quartzite. Fossils found in this series (in the shales above the formation which Walcott has named the Newland limestone member of the Belt terrane) represent the earliest forms of life yet known. Near Neihart the Algonkian period is represented by 4,000 feet of beds, while farther south and west the thickness is much greater.

Overlying the Algonkian rocks conformably are rocks containing Middle Cambrian fossils. North of Neihart they rest directly on the Archean.

WEED,[148] in 1901, describes and maps the geology of the Elkhorn mining district of Montana. Doubtfully referred to the Algonkian are the Turnley hornstones. The lower division is 200 feet thick and consists of shale metamorphosed to a very dense hornstone composed of light-brown biotite and quartz. A bed of impure iron ore 20 to 30 feet thick occurs in the middle lower part of the formation. The quartzitic hornstones overlie the basal beds just noted and are 200 feet thick. The rocks, though well bedded, are very dense and hard and are of a gray-black color, so that they closely resemble the andesites. In color, composition, and relation to the overlying quartzite the rocks correspond to the red Spokane shale of the Belt terrane seen at Whitehall, 20 miles south, at Townsend to the east, and at Helena on the north.

WILLIS,[149] in 1902, describes and maps the stratigraphy and structure of the Lewis and Livingston ranges of the Front Range of the northern Rocky Mountains of Montana and Alberta. The Lewis and Livingston ranges consist of stratified rocks of Algonkian age, as determined on fossils which were found by Weller in the lowest limestone of the series and identified by Walcott as probably being *Beltina danai*, the species of crustacean discovered in the Greyson shales of the Belt Mountains. The Algonkian series consists of limestone, argillite, and quartzite, classified in six formations and aggregating

[a] The Belt formation includes the various lithological members of the Belt terrane which Walcott has named the Chamberlin shale, the Newland limestone, the Greyson shale, the Spokane shale, and the Empire shale.

about 10,700 feet in thickness. The formations are, in downward sequence: Kintla argillite, Sheppard quartzite, Siyeh limestone, Grinnell argillite, Appekunny argillite, and Altyn limestone. There is apparent conformity throughout. The series is so situated with reference to other rocks that no lower or upper stratigraphic limit could be determined. G. M. Dawson classified the strata as Cambrian, Carboniferous, and Triassic, but it is believed that he mistook certain local overthrust faults for unconformities and was misled by lithological resemblances.

Igneous rocks occur sparingly in the Algonkian series. An intrusive sheet of diorite is extensive in the upper limestone formation, and an extrusive flow of diabase caps it.

The Algonkian strata form a syncline whose axis trends west of north. Southwestern dips vary from 5° to 30°. Northeastern dips are generally 30° to 40°, and locally approach or pass verticality. Minor flexures within the syncline are very broad and low. The northeastern limit of the fold is an eroded margin; the southwestern is an anticlinal axis whose western limb is in part eroded, in part thrown down by a normal fault along North Fork Valley. Syncline and anticline are closely related to valley and ridge, respectively, and this relation extends to heights of peaks.

Along its eastern margin the oldest Algonkian formation rests upon Cretaceous rocks. The outcrop of this abnormal contact is deeply sinuous throughout the stretch from St. Mary Lake to Waterton Lake. The structure is described as an overthrust fault, on which the Algonkian series has moved northeastward relatively over the Cretaceous rocks. The displacement on the thrust surface is 7 miles or more, and the vertical throw is estimated at 3,400 feet or more. The thrust surface dips from 0° to 10° SW., and strikes variously from N. to N. 60° W. Thus it is warped, and this warping is found to determine the general outline of the eastern face of the Rocky Mountains, particularly the prominence of Chief Mountain, and the relative position of the Lewis Range, en echelon to the Livingston.

Lindgren, in 1904, reports on a reconnaissance of the Bitterroot and Clearwater mountains of Montana and Idaho. See summary in section 8, Idaho, page 850.

Weed,[150] in 1905, summarizes the development of knowledge concerning the pre-Cambrian geology of Montana.

The investigations of the Hayden Survey, covering the Yellowstone Park and the extreme southwestern part of the State, have led to a grouping of the rocks as Archean and Paleozoic, the oldest beds of the latter being assigned to Silurian. No attempt was made by the investigators of this Survey to differentiate the Algonkian rocks from the crystalline complex. At a later period (1882–83)

Davis and the other geologists of the Northern Transcontinental Survey distinguished the great series of undoubted sedimentary rocks forming the main mass of the Little Belt and Big Belt mountains, classifying this great thickness of 10,000 feet or more of rocks as Lower Cambrian. In 1888 Iddings and Weed published Folio 1 of the Geologic Atlas of the United States. In this publication the Archean complex constituting the nucleus of the mountain ranges lying east of Yellowstone River is described, but no discrimination was made of the thinly banded series of marbles, quartzites, and schists constituting the upper portion of this series of crystalline rocks and lying unconformably beneath the Flathead quartzite, the lowest part of the Paleozoic series. Similar conditions prevail eastward, and have been recognized in the vicinity of Red Lodge, Mont., and extending southward into Wyoming. In the Three Forks quadrangle, which immediately adjoins the Livingston quadrangle on the west, Peale distinguished a series of semicrystalline rocks as the Cherry Creek formation, which he assigns to the Algonkian. This series of rocks occurs on the west side of the Madison River, forming an area 4 miles wide and 8 miles long. The formation consists of crystalline limestones, mica schists, quartz schists, and gneisses, in steeply inclined bands. So far as recognizable, the structure of this series, like that observed south of Livingston, Mont., is conformable with the lamination of the gneisses and granite to the south. These rocks are unconformably overlain by the little-disturbed Cambrian. Similar rocks occur in the Three Forks quadrangle north of Virginia City, but were not discriminated by Peale on the map.

The great series of barren slates found in the Little Belt and Big Belt mountains, and mapped by Davis, are clearly recognizable as sedimentary rocks, and differ very markedly in character from the rocks last described. In mapping the regions lying about the Missouri River it became necessary to name this formation, and after conference Weed and Peale adopted the name Belt formation, or Belt series, for the entire thickness of rocks. These rocks have not been found in contact with the Cherry Creek Algonkian, and in the Little Belt Mountains the old shore line of the Belt formation is clearly recognizable in Archean schists and gneisses wholly unlike the Cherry Creek series, or the unnamed series found south of Livingston. As the Belt series is nowhere in contact with the Cherry Creek, its relatively later age is assigned to it because the former Cherry Creek rocks are extremely metamorphosed and have a structure similar to that of the Archean gneisses. The age of the Belt series is determined by unconformity at the base and the fact that fragments of Archean rocks occur in its basal conglomerate, by the occurrence of middle Cambrian sediments immediately above it with a profound unconformity between, and by a vast difference in the degree of metamorphism between the unaltered Cambrian above and the crystalline complex below.

The Belt series, described as the Belt terrane by Walcott, covers a large part of the region adjacent to the Missouri River, and has been traced northward by Chapman; there seems no reason to doubt, from the lithological similarity, close proximity, and stratigraphic sequence, that the rocks exposed over so large a part of northwestern Montana are identical with the rocks of this formation exposed in the Big Belt and Little Belt ranges and in the main Front Range of the Rocky Mountain area of the Missouri River. The series embraces several distinct formations separated by at least two well-marked unconformities. In a general way it may be described as a series of argillaceous beds varying into quartzites and into impure limestones, the lower rocks showing tilting before the deposition of the later beds. The series as exposed near Neihart, Mont., exhibits a cycle of deposition, beginning with the Neihart quartzites and passing through the Chamberlin shales, Newland limestones, Greyson shales, and Spokane quartzites; beginning again, after a period of erosion, with the Empire shales, and passing through the Helena limestones and the higher beds exposed near Marysville, Mont., and mapped as the Greenhorn shales. These beds form the central core not only of the Big Belt and Little Belt mountains, which are anticlinal uplifts, but also of the Big Valley at Helena, Mont., which is a dome-shaped uplift eroded into the present basin. Followed westward, the rocks are found to be covered by various later formations, but appear at intervals as far west as the South Fork of Bitterroot River, where they rest discordantly upon the underlying Archean (?) gneisses. Along the line of the Northern Pacific Railway the rocks seen between Townsend and Helena are covered by later sediments, across the Continental Divide, but the Algonkian rocks reappear in Hell Gate Canyon and over the broad expanse of the Missoula Valley near the city of that name, continuing westward, with occasional patches of Tertiary and of Paleozoic rocks, to the State line.

Along the Great Northern Railway these Algonkian rocks of the Belt terrane form the high and truly alpine peaks lying between Flathead River and the Front Range. These Belt rocks extend westward beyond the State line, forming all the mountainous country and being covered in the valleys.

The region between the Great Northern Railway and the Canadian boundary was studied by Walcott, Weeks, and Weed in 1894, and by Weed in 1898. This work, which formed the basis for the geologic mapping of the State, seen in recent maps of the United States, accords in general with the conclusions reached by Willis. The latter finds the Lewis and Livingston ranges of the northern Rocky Mountain front of Montana to consist of stratified rocks of the Belt series, the lowest limestone carrying *Beltina danai* of the Greyson shale. The rocks form a north-south syncline, with gentle southwest and steeper (30°–40°) northeast dips, and broad minor flexures, mountain and valley agreeing with saddle and syncline. The rocks are overthrust upon Cretaceous shales from St. Mary to Waterton Lake on the boundary, the thrust having a low dip (0°–10°) southwest, a side shove of 7 miles, and a vertical throw of 3,400 or more feet. Igneous rocks are rare, consisting of a dioritic sheet in the upper limestone and an extrusive flow of diabase capping it.

Walcott,[151] in 1906, discusses the Algonkian formations of northwestern Montana and their correlation with those of northern Idaho and southern British Columbia. Sedimentary beds, correlative with the Belt terrane of the Belt Mountains, extend north of Helena along the Rocky Mountains to the boundary area, where they have been described by Willis. Westward Walcott has followed them as far as Ravalli, in northwestern Montana, and they have been found from here to the Coeur d'Alene district in western Idaho by Calkins and Ransome. A similar series is found by Daly in the section along the international boundary between Kootenay River and the eastern edge of the Tobacco Plains. The Belt series is correlated also with most of Dawson's Adams Lake (Selkirk) series and all of his Nisconlith series. In general fine-grained rocks, including limestones, shales, and sandstones, predominate to the southeast, in the Belt Mountains, the Rocky Mountain front, and westward to Idaho. Coarse conglomerate, grits, and sandstones predominate to the northwest, especially west of Kootenai Valley. The great source of the sediments must have been to the west and northwest of the Kootenai Valley. The eastern shore of the shallow sea afforded very little coarse material. The only place at which the base of the Belt series is seen is in the Belt Mountains, where it comes in contact with the Archean. The Belt series, which is extended broadly to cover all the rocks in these several sections, is overlain unconformably by Middle Cambrian sediments for all of the area except the Lewis Range and the Coeur d'Alene and Kootenai districts. The Bow River series, described by McConnell, seems to be Lower Cambrian and to represent, in part at least, the erosion interval between the Algonkian and the Lower Cambrian.

Calkins, in 1906, discusses reconnaissance observations in northern Idaho and northwestern Montana. See summary in section 8, page 852.

Barrell,[152] in 1907, maps and describes the geology of the Marysville mining district, Montana. All of the sedimentary rocks belong to the Belt group of the Algonkian, which in this area includes five formations grading into one another, including, in order of age: Sandstones and shales of the Greyson formation and the red shales and sandstones of the Spokane formation, both occurring in the northern part of the area. Toward the south the overlying greenish Empire shale is found, transitional into the buff to blue impure Helena limestone. Finally, in the extreme southeast corner, the deep-red Marsh shale overlies the Helena limestone, constituting the uppermost formation of the Belt group and lying unconformably beneath the middle Cambrian quartzite. The latter, however, outcrops beyond the limits of the district, and therefore is not shown on the map. Intrusive into the Belt group is a great batholith of granite 2½ miles long and of variable width, which occupies the center of the district and around the borders of which is concentrated the mineral wealth that has given the district prominence as a mining region. One set of dikes and sheets—the microdiorite of Bald Butte—is of earlier origin than the invasion of the batholith and the formation of the zone of contact metamorphism. Another set of dikes—the Belmont diorite porphyry—is closely connected with the batholithic invasion in point of time, but whether immediately before or after it is not settled. The batholith itself possesses granitic dikes and sheets as outliers, mostly of more acidic composition. Later than the batholith are pegmatites cutting the granite, the Drumlummon porphyry, and a few rare basic dikes.

Walcott,[152a] in 1908, examined the area of pre-Cambrian rocks bounded by the North Fork of Flathead River on the west, the great east-west fault between the Carboniferous and pre-Cambrian south of Crows Nest Pass, British Columbia, on the north, and the Cretaceous of the plains to the east. South of the international boundary he made a reconnaissance for nearly 200 miles in order to correlate the pre-Cambrian formations that he studied in 1905 with those described by Willis and Daly.

The most important result of the work was the proving that the Siyeh limestone of Willis is identical with the Holland and Blackfoot limestones of Walcott. This carries with it the correlation of the Helena limestone with the Siyeh. Walcott also found the upper portion of the lower Cambrian resting unconformably upon the Camp Creek series (Walcott) several thousand feet above the Siyeh limestone. This controverts Daly's theory that the Siyeh limestone is of Cambrian or Ordovician age.

SUMMARY OF PRESENT KNOWLEDGE.

The preceding summary of the pre-Cambrian geology of Montana by Weed is largely historical in treatment. For this reason there is added here only a brief general statement of the essential points in the present knowledge of the pre-Cambrian.

In southwestern Montana the predominant rocks of the pre-Cambrian are granites, gneisses, and schists. The gneissoid granite of this system is magnificently exposed in the canyon of the Madison.

Here the banded gneissoid granite, cut by granitic and basic rocks, has a foliation in the same direction for many miles. Associated with the gneisses along and near Cherry Creek on the west side of the Madison River is an area 8 miles long and 4 miles wide, which consists of crystalline limestones, mica schists, quartz schists, and gneisses, very highly inclined. This is called the Cherry Creek "series." So far as seen, the structure of the series is conformable with the lamination of the gneiss and granite. The apparent conformity of the Cherry Creek series and the gneisses may in future be explained by any one of three hypotheses—obliterated unconformity, downward metamorphism, or intrusion of the gneissic series. The truncated edges of all the above are traversed by the little-disturbed Cambrian.

Besides the Cherry Creek group there is a pre-Cambrian clastic series called the Belt series, ranging up to 10,000 or 12,000, or possibly even 30,000, feet in thickness, resting upon the Archean unconformably. This series is exposed along East Gallatin River, in the canyon of Jefferson River, in Bridger Canyon, in the Little Belt Mountains, northwesterly past Helena into British Columbia, and westward beyond the state boundary into Idaho. (See Pl. I.) In general, fine-grained rocks, including limestones, shales, and sandstones, predominate to the southeast in the Belt Mountains, in the Rocky Mountain front, and westward to Idaho. Coarse conglomerates, grits, and sandstones predominate to the northwest, especially to the west of the Kootenai Valley, which region must have been the great source of the sediments. The Belt series is correlated by Walcott with most of Dawson's Adams Lake (Selkirk) group and all of his Nisconlith group. Middle Cambrian sediments overlie the Belt series unconformably for all the area except the Lewis Range and the Cœur d'Alene and Kootenai districts. The Bow River group seems to be lower Cambrian and is taken by Walcott to represent, in part at least, the erosion interval between the Belt series and the lower Cambrian. The Belt series contains sparse fossils of probable pre-Cambrian age.

While the Cherry Creek group is not anywhere in contact with the Belt series, its extreme metamorphism and its common structure with the gneisses make it highly probable that it is unconformably below the Belt series, since the latter rests upon the truncated edges of the gneisses.

Occupying a position similar to that of the Belt series are great series of sedimentary rocks in the Uinta Mountains, in the Wasatch Mountains, and in British Columbia. These in all probability are contemporaneous with the Belt series, and together mark a continuous area of deposition, and therefore a geological province, in early Cambrian or late Algonkian time. It may be that the area should be extended to include also the Algonkian quartzites of southwestern Colorado and of the Grand Canyon.

The wide extent, thickness, comparative uniformity, and lack of deformation of the Belt series make it unique among the pre-Cambrian series of North America. When first studied it was supposed throughout to be a conformable downward gradation from the Cambrian. Subsequent work showed that in Montana at least there was an actual structural unconformity. This has not been found in the Uintas, the Wasatch, or British Columbia.

Under the classification here used the Belt series is late Algonkian; the Cherry Creek group is probably earlier Algonkian; the Archean is presumably represented by a part of the old granite-gneiss-schist complex of southwestern Montana, but it has not yet been proved to be unconformable below the Cherry Creek group.

SECTION 10. WASHINGTON, OREGON, AND CALIFORNIA.

SUMMARY OF LITERATURE.

WASHINGTON.

Gibbs,[153] in 1855, states that in central Washington, in the valley of the Methow, is found granite, syenite, and gneiss, well characterized and blended with one another. The syenite is often divided by joints so as almost to appear stratified and to give its perpendicular walls the semblance of artificial construction. The gneiss is found both horizontal and displaced by the intrusion of trap. Along Columbia River was found syenite, granite, gneiss, quartzose rocks, talcose slate, and greenstone.

Russell,[154] in 1900, describes the schists of the northern Cascades and states that they are lithologically similar to Archean schists of the eastern portion of North America. Metamorphic rocks of this type on the Pacific coast, however, are known to be of Mesozoic age, and these schists of the Cascades are presumably Paleozoic or post-Paleozoic.

Landes,[155] in 1902, outlines the geology of Washington. Metamorphic rocks of unknown age, but some of them possibly Archean, occupy a large portion of the State, being frequently met with throughout the Cascades, from Stampede Pass northward to the British Columbia boundary, and from near Puget Sound eastward across the Cascade Mountains and the Okanogan highlands to the Idaho line. The ordinary varieties of metamorphic rocks in Washington are gneiss, schist, marble, slate, and quartzite.

Smith (G. O.),[156] in 1903, considers the Easton schist the oldest rock in central Washington, and describes it as commonly a quartz mica rock extremely crumpled and gashed and seamed with quartz.

Hornblende and epidote schists, as well as quartzite, occur in the same formation, so that the Easton schist is believed to contain rocks of both igneous and sedimentary origin. These rocks unconformably underlie metamorphic formations to which a Carboniferous age is provisionally assigned.

SMITH (G. O.) and CALKINS,[157] in 1904, describe the granitoid gneiss and schist of the Columbia River gorge above Wenatchee, which appear older than the supposedly Carboniferous strata in the vicinity of the international boundary. Along the boundary pre-Cretaceous sedimentaries and volcanics were encountered on the west slope of the Cascades, but no evidence is cited to show that these metamorphic rocks are pre-Paleozoic. In the lower Skagit Valley a series of slates, chlorite and glaucophane schists, with ferruginous quartzites and jaspers, is described, but no definite age is assigned to the series.

RANSOME,[132] in 1906, states that in the course of a reconnaissance covering a strip about 10 miles wide along the south side of the international boundary in 1901 he found the northeast corner of the State, east of Pend Oreille River and as far south as Ione, to be occupied by complexly folded, dark siliceous slates and fine-grained crystalline schists, including numerous bands of schistose limestone and occasional beds of quartzite. These rocks are unfossiliferous, as far as known, and seem to be continuous with the schists and gneisses of northwestern Idaho, which, as stated on page 851, are probably pre-Cambrian.

Along Pend Oreille River from Ione to the international boundary are thick masses of limestone which, while intimately associated with the schistose rocks, may possibly be infolded younger beds.

From Pend Oreille River to the Columbia the prevailing rocks are dark siliceous slates, fine-grained fissile schists, and schistose limestone. These highly compressed rocks are tentatively assigned to the Carboniferous by Daly,[a] but fossils are lacking and the series passes with no apparent break into the more conspicuously crystalline and gneissic complex of northwestern Idaho. Considerable masses of gneissic granite are exposed west of Ione and on Deep Creek a few miles east of Northport. The presence of these masses suggests that the schistose rocks between Pend Oreille and Columbia rivers may be much older than the Carboniferous.

West of Columbia River the slaty schists are gradually succeeded by closely compressed conglomerates and greenstone (andesitic) breccias with much greenish tuffaceous slate and some clay slate. These rocks, which are cut by numerous dikes of dioritic porphyry, may be younger than the Algonkian. They are, however, so closely inter-

[a] Summary Rept. Geol. Survey Canada for 1902, 1903, p. 143.

folded with the crystalline schists to the east that only detailed work can establish their real structural relations. Near Kettle River these rocks are overlain by younger, possibly Tertiary, lavas.

Along Kettle River south of Cascade City is exposed granitic gneiss associated with mica schist, quartz schist, and highly metamorphosed crystalline limestone. These rocks extend westward almost to the northward-flowing stretch of the Kettle River between Curlew and Nelson. On lithological grounds they are supposed to be pre-Cambrian.

West of Nelson and Curlew for a distance of 30 miles the prevailing rocks are volcanics of unknown age, resembling somewhat those between Columbia and Kettle rivers. There are probably at least two series present—older, compressed, and somewhat metamorphosed rocks being overlain by what may be a Tertiary andesitic series. Within this area, however, is an island-like mass of gneiss, mica schists, and crystalline schistose limestone, which is about 7 miles wide between Curlew and Midway, and extends as a narrowing band southward, passing a few miles west of Republic. On lithological grounds the gneiss and schistose rocks may be assigned with some probability to the pre-Cambrian.

About 5 miles west of Chesaw, or 10 miles east of Lake Osoyoos, there is a change from much-fissured argillites, slaty green tuffs, fine-grained epidotized eruptives and lenses of limestone to crystalline schists and granitic gneisses. The gneiss widens greatly to the south and becomes the dominant rock between Republic and Okanogan River. It possibly connects with the body of gneiss which crosses Kettle River between Curlew and Midway. It is provisionally regarded as pre-Cambrian, though detailed work is required to establish its relation to the rocks about its borders.

OREGON.

Lindgren,[158] in 1901, describes and maps the geology of the gold belt of the Blue Mountains of Oregon. Gneiss referred to the Archean occurs northwest of Sumpter, above La Belleview mine.

For description of the schists in the Klamath Mountains of Oregon, which are related to the supposedly Algonkian of California, see page 874.

CALIFORNIA, WITH ADJACENT PARTS OF NEVADA AND ARIZONA.

Dana,[159] in 1849, describes various crystalline rocks in the Umpqua and Shasty ranges. These include granite, syenite, porphyry, talcose rocks, and serpentine. The hornblendic and talcose rocks are rarely schistose. Associated with the former rocks are conglomerates and sandstones.

Tyson,[160] in 1850, describes sections in the Sierra Nevada and the Coast Range. The rocks are, first, metamorphic, consisting of those of sedimentary origin, such as slate, but subsequently altered by the effects of heat; and, second, of hypogene rocks, which include granite, trap rocks, and others.

Blake,[5] in 1856, states that the contorted gneisses of the Aquarius Mountains are metamorphic. In the Aztec Mountains the horizontal Carboniferous strata show that they were an ancient granitic uplift. The specimens of granite are of a red or rose color, few or none being white or light gray, in this respect contrasting strongly with the collection made from the Sierra Nevada and the Bernardino Sierra, as well as from those of the Great Basin and along Mohave River. The metamorphic rocks are in all probability not older than the Silurian or Carboniferous. This is certainly the case in the Aquarius Mountains. In the rapid reconnaissance of these disturbed and metamorphic rocks it was not possible to bestow the attention upon them which their obscured condition demands, and it is therefore not possible to assign a dividing line between the truly erupted granitic rocks and those which simulate them but in reality are of sedimentary origin.

Newberry,[161] in 1856, states that in the coast mountains are found occasional protrusions of granite and serpentine. The great mass of the Sierra Nevada is composed of plutonic or volcanic rock, granite, gneiss, mica schists and porphyries, traps, trachyte, etc., with auriferous talcose slates and veins of quartz. The western slope of the Cascade Mountains in one place where crossed is composed of trappean and metamorphic rocks.

Antisell,[162] in 1856, states that in the Coast Range the igneous rocks that form the axis are of two kinds, granitic and trachytic. Granitic and Primary metamorphic rocks are mentioned as occurring at several places in the Coast Range, and in the Cordilleras in many localities. At one locality hornblende gneiss is found.

Blake,[163] in 1857, states that granite is found at points along the coast from Monterey to near the Golden Gate. At the Tejon, in the Sierra Nevada, the rocks now generally classed as metamorphic, such as gneiss, mica schists, hornblende slate, and chlorite slate, are predominant. While these rocks are probably a metamorphosed sediment, the linear arrangement of the minerals is not regarded as satisfactory evidence of it. This structure also appears when the rocks are so far fused as to obliterate the original planes of stratification, and therefore the words strata or stratification in relation to these rocks are avoided, but to designate the lines or layers of minerals the terms planes of structure or lamination are used. At one section was found granite, upon both sides of which is white limestone; next to the latter on one side is quartz rock, which is followed by chlorite slates. If the structural relations were regarded as conclusive evidence, the whole series would necessarily be considered metamorphic; but there is little reason to doubt that the granite is eruptive. The metamorphism in the limestone is complete and resembles the coarsely crystalline white limestone of Sussex County, N. J. There is no indication as to the age of the limestone or quartz rock, but there is some reason to regard them as Carboniferous, for these are the nearest known formations of limestone which are recognizable by fossils. On the section of the Cañada de las Uvas the rocks are similar to those of the western slopes of the Tejon. Along Mohave River the rocks consist of metamorphic slates, very compact and so much changed as to resemble granite. In the Colorado Desert most of the metamorphic rocks are highly laminated and contain lenticular beds of limestone. In the gold region talcose and clay slates are the prevailing rocks, and in general present a low degree of metamorphism. Next to the slate in importance is white crystalline limestone.

Emory,[164] in 1857, states that in southern California there is a great preponderance of crystalline metamorphic granite pertaining to the older Paleozoic series of rocks and an entire absence of any member of the lower Paleozoic or secondary rocks in their regular stratified character. The central axes are represented by somewhat variable granite, assuming in some places a close syenitic texture, while at other places there is a preponderance of mica. Belonging with the granitic series, particularly on the eastern side of the range, are mica and talcose slates.

Newberry,[165] in 1861, describes the great mass of the Peninsular Mountains, east of San Diego, as composed of granitic and gneissoid rocks which are similar to most of the granites of the other systems of the Colorado; that is, a predominance of the feldspathic over the hornblendic ingredients. Where the Colorado cuts through the Chocolate Mountains they are composed of gneisses traversed by veins of granite and quartz. The gneissoid rocks are frequently foliated and much convoluted. Their aspect is such as to lead an observer more readily to refer them to a metamorphic origin than any other rocks seen on the route. The great mass of Monument Mountains is a coarse, massive feldspathic granite. On both sides of the granitic axis are highly metamorphosed conglomerate and sandstone. The principal mass of the Mohave Mountains is composed of white granite, traversed by numerous veins of quartz. The Black Mountains as a whole are characterized by prominence of eruptive rocks, such as massive granite, trap, porphyry, and trachyte, and rarity of gneiss, mica slate, clay slate, etc., which are probably metamorphic. In the lower Colorado Canyon, unconformably below the Potsdam sandstone, is granite, which is cut by veins of quartz and red syenite. This sandstone is somewhat metamorphosed, but its consolidation is not due to volcanic heat, but rather to molecular changes induced by long-continued pressure of the immense mass of superincumbent rocks. The Cerbat Mountains have a core of granite.

Whitney,[166] in 1865, describes the Coast Ranges, the region between the Cañada de las Uvas and Soledad Pass, and the Sierra Nevada, in all of which regions are found granitic and metamorphic rocks.

Granite occurs at many points in the Coast Ranges and is described and figured as breaking through the Cretaceous and Tertiary strata and metamorphosing them.

In the Cañada de las Uvas region, at San Emidio Canyon, occur granite, mica slate, syenite, hornblende slate, and limestone, turned on end and unconformably overlain by unaltered Cretaceous and Tertiary strata. In the Tejon Pass are found mica slate, granite, gneiss, and syenite. Near the fort occurs crystalline limestone associated with mica slate and gneiss, together with magnetic iron ore.

Gilbert,[16] in 1875, states that in the Inyo Range are found syenite, granite, and gneissoid rocks. On its east face quartzites, siliceous schists, green schists, and limestones make the section more than 1,100 feet thick. In the Amargosa Range the Whites Peak series is 11,500 feet thick, and is composed of quartzites, green garnetiferous schists, and siliceous and argillaceous schists. At the base of the section in the Amargosa Range is 900 feet of quartzite resting conformably upon 600 feet of mica schist and chlorite schist. A section at Boundary Canyon 2,500 feet thick is made up of limestones, micaceous and other schists, and quartzites. None of these rocks are regarded as pre-Silurian. Although no fossils are found, the Whites Peak section is presumptively Silurian.

Marcou,[167] in 1876, states that granitic rocks occur in the Sierra Madre in southern California at a number of points. This mountain chain is described as the most ancient of the modern chains of southern California; that is to say, the granite, pegmatite, gneiss, and metamorphic rocks which form its principal mass date from times anterior to the Paleozoic.

Loew,[168] in 1876, states that nearly all the mountain ranges of southern California belong to the Primitive formation. In the San Bernardino Mountains the main mass is granite, accompanying gneiss, mica schist, talcose schist, and Primitive clay slate. The Riverside and Halfway mountains consist of granite and gneiss. At the Mohave Range is a series of Azoic rocks consisting of fine-grained granite, syenite, hornblende schist, and quartzite. At the Panamint Range are Primitive limestone and clay slate as accompaniments of the granite. In the Coahuila Valley eruptive gneiss is found which has metamorphosed the limestone on either side. The gneiss shows by the position of its mica plates a stratification parallel to the limestone layers, indicating the effect of pressure during the consolidation of the injected rock mass. Eruptive syenite occurs in the Buena Vista and Inyo ranges, and eruptive granite at Dead Mountains and in the Opal ranges. Occasionally in the San Bernardino Mountains the granite gives rise to the formation of beds of arkose, a rock in which granitic débris has been recemented, forming a sort of granitic sandstone resembling to some extent granite, but the uniform grain, friability, and rusty surface of the fragments elucidate its true nature.

NEWBERRY,[9] in 1876, states that in the Aquarius Range the Carboniferous strata rest directly upon the granite. In the Cerbat Mountains are found gray granitic rocks upon which rest unchanged Carboniferous strata. In the mountains of the lower Colorado metamorphic rocks are abundant, consisting of gneiss, mica slate and clay slate, talcose slate, and limestone, the latter highly metamorphosed and crystalline, forming marble, and being, so far as observed, wholly destitute of fossils. This metamorphic limestone of the Sierra is suspected to be Carboniferous.

CONKLING,[169] in 1877, states that the ridgelike line of the eastern summit of the Sierra consists entirely of granite, flanked in several places by igneous rocks. In the western summit range are also found granitic rocks.

CONKLING,[170] in 1878, describes portions of western Nevada and eastern California, including a part of the Sierra Range, and finds little aside from metamorphic and igneous rocks. Granite is found at many localities.

BECKER,[171] in 1888, states that granite underlies the Coast Ranges and the Sierra Nevada. The evidence in California is in favor of the hypothesis that the main mass of the underlying granite is primeval. While it is not absolutely certain that Archean rocks occur in California, the unquestionable occurrence of the Archean in Arizona and the similarity of the rocks of southeastern California to those of the adjacent territory make it probable that San Bernardino County is largely Archean. In the Gavilan Range the lowest sedimentary formation is a crystalline limestone, associated with which are rocks of the Archean gneiss type. It is possible that it is a member of the Knoxville series more metamorphosed than usual, but it appears more probable that it is a remnant of some older formation which has perhaps undergone repeated metamorphism. Aside from these the earliest metamorphic rocks of the coast are probably Cretaceous.

MILLS,[172] in 1892, finds in the Sierra Nevada, unconformably below the Mesozoic, eruptive granites and sedimentary slates and quartzites. The latter in places rest and were probably deposited upon the granite, while in other places they are contemporaneous and embedded within it. The quartzites are held to be silicified phases of the slates. These rocks in age may run from Archean to the Paleozoic, and some of them may be early Mesozoic.

LAWSON,[173] in 1893, describes the Santa Lucia granite of Carmelo Bay as resting unconformably below the sedimentary rocks (Miocene) of the Carmelo series. At the base of the latter is a fine basal conglomerate. Across the Bay of Monterey, in the Santa Cruz Range, granite without doubt of the same geological range bears a similar relation to rocks which are of not later age than Cretaceous. The granite is therefore, at the latest, of pre-Cretaceous age.

HERSHEY,[174] in 1901, describes the schistose rocks of the Klamath Mountains in northwestern California. On the whole it seems impracticable to fix upon any particular part of the time between the Archean and the Devonian as the period of deposition of the Klamath schists, but it is believed that the evidence favors the earlier or Algonkian portion rather than the Cambrian or Silurian portion.

HERSHEY,[175] in 1902, describes the results of a brief examination of the Fraser Mountain and Sierra Pelona regions, and portions of the Tehachapai, Sierra Madre, and San Bernardino ranges, together with a rather extended section of Mohave Desert, all comprised in the counties of Los Angeles, Ventura, Kern, and San Bernardino, of California. The crystalline rocks are discriminated under the following heads:

1. The Pelona schist series.
2. The gneiss series.
3. The rocks of Fraser Mountain and vicinity.
4. The Mesozoic granites.
5. The Ravenna plutonic series.
6. The gneiss near Barstow.
7. The quartzite-limestone series of Oro Grande.
8. The schists in Cajon Pass.

The Pelona schist series and the adjacent gneisses, the rocks of Fraser Mountain and vicinity, and the gneiss near Barstow are tentatively correlated with the Abrams schist of the Klamath region in a general way, and are considered pre-Paleozoic, perhaps in part Archean and in part Algonkian.

HERSHEY,[176] in 1903, discusses the structure of the southern portion of the Klamath Mountains of California. The oldest rocks in the mountains west of Sacramento River are the Abrams mica schists, 1,000 feet thick, and overlying it the Salmon hornblende schist, known to be at least 2,500 feet thick, both of them supposed to be of pre-Cambrian age, probably Algonkian and possibly Archean. The Abrams mica schist is a sedimentary rock and the Salmon hornblende schist is a metamorphosed volcanic ash. The Klamath schists form the central ridge of the Klamath region. They are bordered on the west by a great, unsymmetrical geosyncline, and on the east by the western limb of another great geosyncline. The first geosyncline is limited on the west by another belt of schist, chiefly the

Abrams mica schist, which forms the South Fork Mountain, and is prolonged northwestward to and probably across the Klamath River near Weitchpec. The sandstones of the Coast Range region adjoin this schist belt on the west. According to Diller, toward the north, approaching Klamath River, long narrow belts of schist alternate with narrow belts of sandstone, the latter dipping eastward as though going under the schists. This apparent anomaly is evidently due to a series of faults. It is further evident that the Coast Range formations have buried the western portion of the schist belt, which may extend, immediately under the sandstone, far toward the coast.

The eastern schist belt emerges from beneath the Cretaceous sandstones and shales in the Sacramento Valley west of Ono, with a width of 8 miles, which gradually increases as it advances northward to a maximum of about 12 miles west of Scott Valley. Southward from Trinity River the pre-Paleozoic area is occupied chiefly by the Abrams mica schist, the hornblende schist being confined to narrow strips, but northward from Trinity River the hornblende schist spreads out and finally nearly excludes the mica schist, as in the valley of the South Fork of Salmon River. Still farther north, in the mountains west of Scott Valley, the mica schist has again asserted its supremacy.

Diller,[177] in 1905, summarizes the geology of the crystalline rocks of northern California. The oldest rocks exposed in the northern end of the Sierra Nevada contain characteristic Silurian, possibly Ordovician, fossils. There is a very small area of them, with no characteristic Devonian, brought up by an overthrust fault to the east of Grizzly Ridge, near Taylorsville.[a] Northwest, beyond the Sierra, in the Klamath Mountains, the oldest fossiliferous rocks are of Devonian age.[b] They are widely distributed and where not bounded by igneous rocks are limited on the one hand by Carboniferous sediments and on the other by crystalline schists, which Hershey [c] referred in a general way to about the horizon of the Algonkian. Although the Devonian is well established in the Klamath Mountains, with older rocks beneath, no trace of Silurian fossils has been found there. The presence of Silurian and Devonian sediments in the northern part of the State, both but slightly altered, precludes the metamorphism of Silurian strata in the Klamath Mountains before the deposition of the Devonian and affords a good reason for regarding the schists which underlie the Devonian as pre-Silurian in age and possibly older than the Ordovician.

The pre-Silurian rocks of the Klamath Mountains are chiefly mica schists and occur in three distinct belts, one in the South Fork

[a] Bull. Geol. Soc. America, vol. 3, 1892, pp. 369–394.

[b] Bull. U. S. Geol. Survey No. 196, 1902, p. 63. Also Am. Jour. Sci., 4th ser., vol. 15, 1903, pp. 342–362.

[c] Am. Geologist, vol. 27, 1901, pp. 226–230, 239–245.

Mountain, another in the Salmon Mountains, both subordinate parts of the Klamath Mountains in California, and a third, somewhat doubtful, at the northern end of the Klamath Mountains on Rogue River in Oregon. The two lines of outcrop at their southern ends are about 40 miles apart and approximately parallel, running northwest-southeast. The first belt runs northwest from the Sacramento Valley through the Yallabally and South Fork mountains to the sea, a distance of more than 100 miles, with an average width of somewhat more than 5 miles. The prevailing rock is a gray or greenish-gray, more or less silky mica schist in which the mica is sericite. Although in well-defined folia and fibers, giving the mass a decided schistose structure, the mica is not well crystallized in distinct scales. The quartz is generally in excess of the mica, and the mass is locally full of quartz veins. Along the western border of this belt in places is a greenish, more or less schistose, rock whose relations are not clearly understood. It is composed chiefly of quartz and epidote, as if a product of contact metamorphism. The long narrow belt of mica schist of South Fork Mountain is bounded on the southwest by unaltered sandstones, shales, and conglomerates of Mesozoic, in part Cretaceous, age, but on the northeast, the direction in which the crumpled schistose structure generally dips, it is limited by a broad belt of Devonian sediments mingled in a very perplexing fashion with an extensive body of plutonic and volcanic rocks.

The second or Salmon Mountain belt is somewhat less regular, extending from Bully Choop Mountain northwest by Weaverville into the Salmon Mountains, where it appears to turn northeasterly toward Yreka. The mica schist [a] of this belt, occasionally containing thin limestones, is associated with hornblende schist,[b] which in the vicinity of Weaverville and Bully Choop appears to be for the most part a metamorphosed igneous rock, but in certain localities Hershey finds evidence of its derivation from sediments overlying the mica schist, with a total thickness for both schists of 3,500 feet.

The third schist area of the Klamath Mountains is in Oregon, extending north beyond Rogue River into the Port Orford region, where it has been definitely mapped [c] as the Colebrook formation. The principal rock is sericite schist, associated with phyllites and beds which are clearly fragmental, of sedimentary origin. These rocks lie unconformably beneath the Knoxville beds, and while it is certain only that they were metamorphosed in pre-Cretaceous time, it is possible that they are of the same age as the schists of California toward which the exposure extends, at least as far south as Smith River.

[a] Abrams mica schist of Hershey, op. cit., p. 226.
[b] Salmon hornblende schist of Hershey, op. cit., p. 228.
[c] Geologic Atlas U. S., Port Orford folio (No. 89), 1903.

SECTION 11. BRITISH COLUMBIA AND YUKON.

SUMMARY OF LITERATURE.

Selwyn,[178] in 1877, in a report on exploration in British Columbia, separates the rocks into five divisions. Division 4 consists of semi-crystalline rocks, among which are limestones, shales, mica schists, and quartzites, which appear to have obscure fossils. The age of these rocks is not clearly determined. Division 5 consists of granitic rocks.

Macoun,[179] in 1877, finds granite gneiss and gneiss a few miles up the Quatre Fourches River, which are referred to the Laurentian.

Dawson (G. M.),[180] in 1877, states that a crystalline series occurs in the Cascade Mountains about Eagle and Tatla lakes. These are chiefly highly crystalline gneisses, granites, and diorites.

Dawson (G. M.),[181] in 1879, describes in some detail the Cascade crystalline series, which are referred to the Carboniferous period. The only rocks tentatively referred to the Laurentian are crystalline rocks of Shuswap Lake and the gold range, which comprise gneisses, greenstones, schists, limestones, and granites.

Bauerman,[182] in 1885, describes, near the forty-ninth parallel, west of the Rocky Mountains, large areas of crystalline rocks, among which are granites, gneisses, basalt, etc. The gneiss of Spokane resembles the typical Laurentian gneiss of Canada. The metamorphic slates and greenstones perhaps belong to the Huronian.

Dawson (G. M.),[183] in 1886, in a report on the portion of the Rocky Mountains between latitudes 49° and 50° 30′, places in the Cambrian the lowest rocks found. These comprise quartzite, quartzitic shales, argillites, limestones, and conglomerates. One section, between South Kootenai Pass and Flathead River, has a maximum thickness of more than 11,000 feet. These rocks are apparently destitute of fossils and are compared in their lithological character with the Cambrian of the Wasatch, but they have a still closer resemblance to the Chuar and Grand Canyon groups of Colorado River.

McConnell,[184] in 1887, describes the Bow River series in the eastern part of the Rocky Mountains. It consists of dark-colored argillites, associated with sandstones, quartzites, and conglomerates. The base is not seen, but the part exposed has an estimated thickness of 11,000 feet. The argillites are occasionally cleaved and have scales of mica often developed along the divisional planes. The only fossils obtained from this formation are a couple of trilobitic impressions, one of which was identified by Walcott as *Olenellus gilberti*.

Bowman,[185] in 1889, states that certain schists are found in the Cariboo gold belt of British Columbia, which are referred to the lower Paleozoic. These consist in the main of slates and sandstones, the total thickness being placed in the neighborhood of 5,000 to 8,000 feet. No fossils are found, and their position as lower Paleozoic is tentative. In the alpine region of Cariboo are found gneisses, granites, and quartzites, which resemble the characteristic rocks of the Archean. Associated with these are lower granitic rocks. The entire crystalline series of the gold region of Cariboo is lithologically identical, as near as can be described in general terms, with the rocks of the pre-Cambrian and Cambrian gold regions of eastern Canada. The gneissic and schistose type of rocks of the Mount Stevenson group especially (supposed to represent the lowest horizon, on account of their association with granite in a central and massive mountain group) finds lithological representatives in the pre-Cambrian rocks of the eastern provinces of the Dominion and in the Appalachian axis.

Dawson (G. M.),[186] in 1891, describes a section in the Selkirk Range and compares it with a section of the interior plateau region at Kootenai and Adams lakes and on the west side of the Rocky Mountains. The sections are given and correlated as follows:

Provisional comparative table of formations met with (1) in the eastern border of the interior plateau of British Columbia, (2) in the Selkirk Range, and (3) on the western side of the adjacent portion of the Rocky Mountain ranges.

1. Section on Kootenai and Adams lakes.		2. Section in the Selkirk Range on line of Canadian Pacific Railway.		3. Section in the Rocky Mountains (west side of range, McConnell).		
	Feet.		*Feet.*		*Feet.*	
	6. Greenish and gray schists, with limestone .... 2,000 5. Limestone or marble with black, glossy argillites and some gray schists........ 2,500		Quartzites, with gray schists and some limestone. Black shaly argillites, limestone, and gray schists.		*Halysites* beds, dolomites, and quartzites 1,300 or more. Graptolite-bearing shales. Black fissile argillites, with some limestone 1,500	Cambro-Silurian and Silurian.
Adams Lake series.	4. Chiefly greenish, with some gray schists .. 4,050 3. Chiefly gray, with some greenish schists........ 8,550	Selkirk series.	Gray schists and gray quartzites, with some quartzose conglomerate and interbedded blackish argillites, the last chiefly toward the base 25,000	Castle Mountain group.	Greenish and gray calc schists and greenish and reddish shales and slates, with some dolomitic limestone .... 10,000 (probably).	Cambrian.
Nisconlith series.	2. Black, shaly, or schistose argillite, with some limestone .... 1,000 or more.	Nisconlith series.	Blackish argillite schists and phyllites, generally calcareous, with some beds of limestone and quartzite 15,000	Bow River series.	Dark argillites, with some quartzites and conglomerates, the latter particularly toward the summit. Base not seen ...... 10,000 or more.	
Shuswap series.	1. Mica schists, gneisses, and marbles ...... 5,000 or more.	Shuswap series.	Gray gneissic rocks and coarse mica schists .... 5,000 or more.			Archean.

Associated with the Archean schists are certain granitoid rocks which may represent either portions of the schists in which the bedding has been obliterated or very ancient intrusives. Besides these there is at least one later series of intrusive granites which are probably later than most of the Paleozoic rocks. The Shuswap series of the Adams Lake section appears to be traceable on its line of strike into diabases and diabase rocks, which are often agglomerates and pass into volcanic ash rocks. In the Shuswap series of the Selkirk nearly half of the entire mass of the rocks exposed consists of intrusive or vein granite with pegmatitic tendencies. In the Nisconlith series the lamination is often true bedding, but in some places a slaty cleavage is developed. In the Castle Mountain group and the upper 3,000 feet of the Bow River series of the Rock Mountain section the *Olenellus* fauna is found. Nowhere in any of the sections were unconformities seen. In sections 1 and 2 no fossils have been discovered. The correlations are made upon relative positions and lithological grounds. Between the Shuswap and overlying series there is believed to be a great time break, for this lower series is of a markedly more crystalline character, and the numerous granite veins which everywhere cut it at no point enter the overlying Cambrian strata. The rocks placed in the Cambrian are, then, 40,000 feet thick. The use of the term Algonkian to designate the rocks conformably below the *Olenellus* fauna is objected to, it being more philosophical to include, for the present at least, the whole of this great conformable mass of rocks to its base under the name Cambrian.

McConnell,[187] in 1896, reports on an exploration of Finlay and Omenica rivers in the Rocky Mountains of western Canada. The Archean[a] rocks of the district consist of a series of well-foliated mica gneisses, mica schists, hornblende and actinolite schists, quartzose schists, and crystalline limestones. The rocks of the series are usually evenly bedded, and conform in dip to the overlying formations. To the series the local term Shuswap is applied.

Shuswap rocks are found on both sides of Finlay River from its mouth up to its junction with the Ingenica. North of this point the formation divides. The eastern limb follows the eastern slope of the Finlay Valley northwestward to the Quadacha and for some distance beyond. It has a width of 4 miles at Pauls Branch, where it forms the most westerly range of the Rocky Mountains. This width decreases toward the north and increases toward the south. The western limb bends away from the Finlay above the Ingenica, but crosses it again at the great bend which the Finlay describes after leaving the Rocky Mountains, and continues on to the north. The width of this band was not ascertained, as its western boundary was not reached.

[a] In conformity with the usage of Canadian geologists, Archean is above used in the sense of pre-Cambrian.

Another area of Shuswap rocks, separated from the first by a band of limestones, occurs on Omenica River above the Oslinca. The band has a width of 10 miles.

The Shuswap series is overlain by Lower Paleozoic strata.

DAWSON,[188] in 1901, describes the geology of the Rocky Mountain region in Canada. The oldest rocks of the region belong to the Shuswap series, of Archean [a] age. The Shuswap series characterizes considerable areas of the Selkirk, Columbia, and adjacent ranges in the southern part of British Columbia. It is known also in the Cariboo Mountains and near the sources of the North Thompson and Fraser, about latitude 53°. It is again well developed on Finlay River, where the country has been geologically examined, between the parallels of latitude 56 and 57. Northward to this point these rocks appear to be confined to a belt lying west of the Laramide Range and to come to the surface seldom, if at all, in that range. Farther north similar rocks [b] occur in the Yukon district in several ranges lying more to the west, but still with nearly identical characters, in so far as they are known. The Shuswap series includes highly metamorphosed sediments with perhaps the addition of contemporaneous bedded volcanic materials. They are grayish mica gneisses, with some garnetiferous and hornblendic gneisses, glittering mica schists, crystalline limestones, and quartzites. Gneisses in association with the last-mentioned rocks often become highly calcareous or siliceous and contain scales of graphite, which are also often present in the limestones. These bedded materials are, however, associated with a much greater volume of mica schists and gneisses of more massive appearance, most of which are evidently foliated plutonic rocks, and are often found to pass into unfoliated granites. The association of these different classes of rocks is so close that it may never be possible to separate them on the map over any considerable area. The granites may often have been truly eruptive in origin, but the frequent recurrence of quartzites among them in some regions indicates that they are, at least in part, the result of a further alteration of the bedded rocks. The original bedded portions of the series closely resemble those of the Grenville series of the Province of Quebec, and the associated gneisses resemble the Fundamental gneiss of the same region. The greatest thickness of the Shuswap rocks so far measured, where there is no suspicion of repetition, on Kootenai Lake, is about 5,000 feet, but even here there are doubtless included considerable intercalations of foliated eruptives.

To the Cambrian are assigned McConnells Bow River series, the Nisconlith series of the Selkirk region to the west, and the Adams

[a] Pre-Cambrian. [b] Probably Paleozoic.—AUTHORS.

Lake series in the vicinity of Shuswap Lake. The upper limit of the Nisconlith series is believed to be somewhat below that assigned on lithological grounds to the Bow River series. The Adams Lake series lie above the Nisconlith. The Nisconlith series, resting upon the Shuswap series, consists of 15,000 feet of dark-gray or blackish argillite schists or phyllites, usually calcareous, and toward the base with one or more beds of nearly pure limestone and a considerable thickness of gray flaggy quartzites. These beds have also been recognized in the southern part of the West Kootenai district and in the western portion of the interior plateau of British Columbia. The Adams Lake series consists chiefly of green and gray chloritic, felspathic, sericitic, and sometimes nacreous schists, greenish colors preponderating in the lower and gray in the upper parts of the section.

McConnell,[189] in 1902, describes the granite gneiss of the upper part of the Yukon Valley, extending from Nordenskiold River in a northwesterly direction across the White River valley to the Tanana and down this stream to near the mouth of Delta River, a total distance of about 380 miles, and concludes that part of the gneisses at least must be regarded as intrusive through, and therefore younger than, the clastic schists associated with them.[a] It is still possible, however, as the work done so far has been largely of an exploratory character, that older gneisses may be present in the district, but no evidence of this was obtained in the course of the investigation.

McConnell,[190] in 1902, 1903, 1904, and 1905, summarizes the results of his exploration in the Yukon territory and makes frequent reference to the character and distribution of the schists, gneisses, and granites in this region, but expresses no opinion as to whether they are of pre-Cambrian or post-Cambrian age. The general tendency of recent work has been to throw emphasis upon the Cambrian or post-Cambrian age of such rocks.

Daly,[191] in 1902, 1903, 1904, and 1905, reports on the geology of the international boundary region. West of Midway is a great group of phyllites, slates, quartzites, chloritic slates, and amphibolites, with highly altered limestone and true volcanic bands, and probably also crystalline limestone, in which no fossils were found. Intrusive into this is a great batholith of granite, granodiorite, and quartz diorite.

The southern Selkirk country, between Salmon River and the western boundary crossing of Kootenai River, is underlain in its eastern part by a great series of crystalline schists—biotite schist,

[a] It might be added that Prindle's investigations in the Yukon-Tanana province confirm the work of McConnell in indicating the intrusive characteristics of the granite forming the so-called "basal complex." (Unpublished notes.)

sericite schist, phyllite, quartzite, and quartz schist, with many bands of yellowish-weathering siliceous marbles—cut by thick sills and dikes of dioritic rock, metamorphosed into an amphibolitic condition, and by a batholith of coarse porphyritic granite, which crosses the boundary from Idaho and forms the ridge of Rykert Mountain at the western slope of the Kootenai Valley trough. The western half of the region is for the most part occupied by a younger conformable group of formations, including thick bands of coarse conglomerate, arkoses, volcanic breccias and flows, quartzites, sandstones, and slates, with rare, thin intercalations of fine-grained crystalline limestone. From Port Hill, Idaho, eastward to the eastern edge of the Tobacco Plains is a great group of conformable quartzites and argillites, which has been divided into four series. The lowest series, the Creston quartzite, is composed of 9,500 feet of wonderfully homogeneous, highly indurated, thick-platy, gray sandstones. Overlying the Creston quartzite is the Kitchener quartzite, a second series of ancient, hard sandstones and interbedded argillites, carrying a high proportion of disseminated iron oxides. These rusty rocks are relatively thin bedded and bear very abundant sun cracks and ripple marks on horizons ranging from top to bottom of the series. The thickness of the Kitchener quartzite is about 7,400 feet. It is itself conformably overlain by at least 3,200 feet of thin-bedded, red and gray argillaceous strata, which, together with subordinate thin beds of light-gray quartzites, make up the formation which Daly calls the Moyie argillite. The youngest member of the four sedimentary divisions is the Yahk quartzite, composed of white to gray indurated sandstones, bedded in thin to medium courses. The top of this series was not seen; the whole thickness of conformable strata is nearly 20,000 feet. Neither the bottom of the Creston quartzite nor the top of the Yahk quartzite appearing in the sections, it is certain that this great thickness is only a minimum.

This is a continuation of the sedimentary series mapped in the area immediately west of the Kootenai at Port Hill. There the strata corresponding to the Creston quartzite are conglomerates, grits, and coarse sandstones, as well as fine-grained sandstones, and are thus, on the whole, notably coarser than they were found to be anywhere in this season's belt. The equivalent of the Kitchener quartzite is less strongly charged with argillaceous beds than is the Kitchener quartzite east of the Kootenai.

These facts point to the conclusion that the shore line whence the materials composing the stratified formations were derived lay to the westward and that the open sea and deeper water lay to the eastward of the western crossing of Kootenai River at the international boundary. This conclusion was strikingly confirmed on carrying the section toward Gateway. It was found that both the Creston quartzite and the Kitchener quartzite gradually become charged with interleaved beds of calcareous quartzite, calcareous argillite, and siliceous limestone, betokening open-water conditions during the formation of these sediments. The nearest relatives of the Creston and Kitchener quartzites in the Rockies are respectively the two thick members of the Altyn limestone delimited by Willis, who, in the year 1901, carried out a reconnaissance survey of the boundary belt on the Montana side.[a] No fossils have as yet been found in these old rocks of the Purcell Range, but fossils of so-called Algonkian age were discovered in the Altyn limestone.

Associated with these rocks are lava flows, volcanic tuffs, and gabbro sills.

See further summaries in sections 8 and 9, Idaho and Montana, pages 849-865.

SUMMARY OF PRESENT KNOWLEDGE.

Dawson's Shuswap "series" includes granites and gneisses, which he regards as similar to the fundamental gneiss of the original Laurentian area, and altered sediments associated with the gneisses and schists, which he regards as similar to the Grenville series of the same region. The distribution and characters of the Shuswap group are reviewed by Dawson in the article above summarized. It is now known that a part of the Shuswap group is of Paleozoic or later age. The true pre-Cambrian rocks included in the Shuswap group may represent both the Archean and the Algonkian.

Extending northward from the international boundary is the continuation of the little deformed or metamorphosed Belt sediments, Algonkian, of Montana. Along the boundary it has been described by Daly. To the north it is believed by Walcott to be represented by Dawson's Nisconlith "series" and a part of his Adams Lake "series," which unconformably overlie the Shuswap group. Daly and Walcott call attention to the change in the character of the sediments from west to east, agreeing that the source of the sediments probably lay to the west of Kootenai Lake. The Bow River group of McConnell is lower Cambrian and may represent in part continuous sedimentation between the Belt Algonkian and the Cambrian. Walcott, in 1907, found *Olenellus* fauna down through 2,000 feet of sediments in the Bow River group. The limits of the Belt Algonkian of British Columbia are not known, for it has been grouped with true Cambrian sediments and mapped as Cambrian. The outlines given on the accompanying map (Pl. I) are very general ones.

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[a] Bull. Geol. Soc. America, vol. 13, 1902, p. 305.

SECTION 12. ALASKA.

SUMMARY OF PRESENT KNOWLEDGE.

The following summary has been prepared by Alfred H. Brooks:

INTRODUCTION.

As the systematic investigations of the geology of Alaska have been carried on for less than a decade and there remain many large almost unexplored areas in the Territory, the conclusions herein presented[a] must be regarded as tentative. The work having been directed along economic lines, considerable attention has been paid to the metamorphic rocks which are the source of the gold, but the problems they present are complex. Few definite statements regarding their succession and structure can be made.

No positive evidence has yet been found of the presence of pre-Cambrian rocks in Alaska, but there are many facts which have been interpreted to indicate such a conclusion. A series of gneisses and mica schists in the Yukon basin, formerly accepted as the base of the stratigraphic succession and provisionally referred to the Archean as this term is used by the United States Geological Survey, are now known to be chiefly altered intrusives. These gneisses are associated with a great complex of metamorphic sediments, intruded by many igneous rocks, whose age and stratigraphic relations are still largely in doubt. Fossils from some of these metamorphic rocks range in age from the Ordovician to the Carboniferous and possibly to the Triassic. Eliminating, however, all of the rocks which, on direct or indirect evidence, are assignable to the Paleozoic, there still remain vast thicknesses of metamorphic sediments whose age is indeterminable and may be pre-Cambrian.

Therefore, though little is known of the oldest horizons, the areas to which they are probably limited are fairly well defined. As part of the Paleozoic and even the Mesozoic rocks have been highly metamorphosed and may include pre-Cambrian horizons, it becomes necessary here to consider briefly all of the areas of metamorphic rocks, but detailed discussion will be limited to those terranes which seem the most likely to include pre-Cambrian rocks.

Of Alaska's 586,400 square miles, less than 150,000 have been geologically mapped, but there are random notes on much of the remainder, and these, together with the inferences drawn from known areas, form the basis for four subdivisions. The youngest embraces all those areas believed to be occupied by rocks which include no pre-Cambrian and no metamorphic horizons. In the next younger divi-

[a] This paper is in part abstracted from The geography and geology of Alaska, by Alfred H. Brooks: Prof. Paper U. S. Geol. Survey No. 45, 1906.

sion are the metamorphic rocks, which may, but probably do not, include any pre-Cambrian horizons. The metamorphic rocks of undetermined age, believed to be in part Paleozoic, though the definite proof is still wanting, are thrown in a third group, and it is in this that pre-Cambrian sediments should be sought, though their presence has not been established.

ARCHEAN.

Dawson has mapped a number of elliptical areas of gneissoid[a] rocks which have a general linear arrangement, stretching from southern British Columbia to Alaska, and included in these his Shuswap "series," which is made up not only of gneisses and crystalline schists, but also of crystalline limestones and quartzites. He points out their lithological and structural similarity to the Grenville[b] series of eastern Canada, and provisionally assigns them to the Archean.[c] It appears to the writer that such criteria of metamorphic rocks can have little weight, though the conclusion that these gneisses belong to the basal complex of western Canada appears to be borne out by the general structural relations. Whether or not this complex will eventually be found to include sedimentary beds is a question which must be left in abeyance for the present. The fact that the older sedimentary terranes of this province sometimes include crystalline schists and sheared eruptives makes a lithologic determination of Archean age of doubtful value.

The northernmost of these gneissoid areas stretches into Alaska between the Tanana and the Yukon and is well exposed along lower White River.[d] Here is a complex of gneisses and mica schists, with massive and schistose and basic and acidic intrusives, characterized by being highly crystalline. In general, it may be said to resemble the rocks which in other regions are usually assigned to the Archean. McConnell[e] has recently suggested terming the gneissic rocks of the Yukon basin the Pelly gneisses. It is significant that, as studies and mapping progress, the areas of the basal gneisses have been much reduced, for the rocks first assigned to the Archean have proved to be in part metamorphosed Paleozoic sediments and in part sheared intrusive eruptions in the Paleozoic terranes. McConnell[f] has shown that some of the granites which have been classed as basal are intru-

[a] Dawson, G. M., Geological record of the Rocky Mountain region in Canada: Bull. Geol. Soc. America, vol. 12, 1901, pp. 62–64. Geological map of Dominion of Canada (Western sheet No. 783), Geol. Survey Canada.

[b] Op. cit., p. 63.

[c] In the sense of pre-Cambrian, following the Canadian usage.

[d] Brooks, Alfred H., Reconnaissance of the Tanana and White river basins: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 7, 1900, pp. 460–466.

[e] Personal letter to the writer.

[f] McConnell, R. G., The so-called basal granite of the Yukon: Am. Geologist, vol. 30, 1902, pp. 55–62.

sive in the sedimentary series, and this is borne out by the latest studies of Prindle in the Yukon-Tanana region. On the earlier reconnaissance maps[a] of the Yukon-Tanana region extensive areas of Archean gneisses and basal granites are indicated. The later and more detailed studies of this field by Prindle[b] have shown these maps to be at fault, for it appears that the gneisses in this belt are chiefly altered igneous rocks intruded in the sediments.

In the course of an exploration[c] in the Mount McKinley region the writer crossed a belt of gneisses south of the Tanana near the head of the Cantwell, but there was no opportunity for detailed studies. The typical rock of this area is a coarse augen gneiss identical with that found in the gneissic complex of the upper Tanana. These rocks appear to be altered eruptives, associated with Paleozoic sediments.

A small area of gneissoid granites and some mica schists in the lower Chandalar River basin north of the Yukon were assigned by Schrader[d] to a basement complex. The evidence presented by him indicates that they may equally well be sheared intrusives, and hence they are not here included with the Archean.

Gneisses are also reported by Spurr[e] in the Kuiu Mountains east of the lower Yukon, and Collier[f] observed gneissoid rocks occurring west of the Yukon, near the mouth of Melozi River. Both of these, in a general way, lie in the extension of the gneissic belts already described and are here included in the metamorphic terranes.

On the first geological map of any part of Alaska, published over half a century ago, Grewingk[g] indicated a belt of gneissic rocks extending along the backbone of the Alaska Peninsula. These he assigned to the "Primitive" rocks. Spurr[h] describes this as a pre-Jurassic basal granite. The recent work of Martin[i] goes to show that this is probably an igneous complex which was intruded during early Mesozoic time.

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[a] Spurr, J. E., The geology of the Yukon gold district: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1898, Pl. XXXVIII, p. 252. Brooks, Alfred H., A reconnaissance in the Tanana and White river basins: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 7, 1900, map 24, p. 460. Brooks, Alfred H., A reconnaissance from Pyramid Harbor to Eagle City: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, Pl. XLVII, p. 356.

[b] L. M. Prindle's final results have not been published. Some account of the geology of this region is contained in The gold placers of the Fortymile, Birch Creek, and Fairbanks districts: Bull. U. S. Geol. Survey No. 251, 1905, pp. 23–38.

[c] The final report is in preparation. An abstract entitled "A reconnaissance in the Mount McKinley region, Alaska," was published in Science, new ser., vol. 16, 1902, pp. 985–986.

[d] Schrader, F. C., A reconnaissance along Chandlar and Koyukuk rivers: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, pp. 471–472.

[e] Spurr, J. E., A reconnaissance in southwestern Alaska: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 7, 1900, pp. 234, 235.

[f] Collier, A. J., The geology of Yukon River. In preparation.

[g] Grewingk, C., Beiträge zur Kentnisse der orographischen und geognostischen Beschaffenheit der Northwest Küste Amerikas, mit den anliegenden Inseln, St. Petersburg, 1850.

[h] Op. cit., pp. 233–234.

[i] Martin, G. C., The geology of Alaska Peninsula. In preparation.

The information now at hand points to the absence of a pre-Cambrian complex in Alaska that may be assigned to the Archean. The rocks formerly assigned to the Archean have been found for the most part to be altered igneous rocks intruded into what are chiefly Paleozoic sediments.

METAMORPHIC SEDIMENTS OF UNDETERMINED AGE.

The oldest sediments of the province form a part of a complex metamorphic series of which little is known except their general distribution. These form a broad belt, in many places broken by areas of younger rocks, which stretches from British Columbia across central Alaska and northwestward toward Bering Strait. In this are included rocks of diverse lithological types and ranging in age from Ordovician, probably the Cambrian, or pre-Cambrian, through the Paleozoic column, but are chiefly pre-Devonian. It is by no means impossible that even some Mesozoic terranes may occur in this great complex, but little has been accomplished toward its differentiation and mapping.

In the Yukon-Tanana region a series of closely folded siliceous schists, phyllites, and quartzites, associated with some crystalline limestones, appears to include the oldest sediments. According to Spurr,[a] this series, called the Birch Creek schist, typified by highly arenaceous sediments, often carrying graphite, occurs above the arkose conglomerate. Spurr's estimate of 25,000 feet thickness for these rocks is probably much too great, for Prindle's[b] more detailed studies in the same field have shown that the folding is so complex as almost to defy accurate measurements. Field studies made in 1906 go to show that the Birch Creek schist is probably unconformably overlain by Ordovician limestones.

The arenaceous sediments pass gradually upward into calcareous rocks and these are succeeded by crystalline limestones interbedded with quartzites. The latter, called the Fortymile "series" by Spurr,[c] are terranes typically made up of marbles and quartzites, with hornblende, garnetiferous, and sometimes graphitic schists. Igneous intrusives are abundant in both the Birch Creek schist and the Fortymile "series," as are also quartz veins, the latter being the source of the placer gold. The Rampart "series," probably of Devonian age, appears to overlie these two terranes unconformably.

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[a] Spurr, J. E., The geology of the Yukon gold district: Eighteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1898, pp. 140–145.

[b] Prindle, L. M., The gold placers of the Fortymile, Birch Creek, and Fairbanks regions: Bull. U. S. Geol. Survey No. 251, 1905.

[c] Op. cit., pp. 145–154.

McConnell's studies of the Klondike stratigraphy[a] can be briefly summarized as follows:

Stratified and foliated rocks, mostly Paleozoic.	Moose Hide group—Green igneous rocks, both massive and schistose.
	Klondike series—Micaceous and feldspathic schists, probably altered eruptives.
	Hunker series—Graphitic schists, some limestones, dolomites, and green schists.
	Indian River series—Slates and quartz schists passing into mica schists, with some limestone.

Though this succession is by no means identical with that described by Spurr, 100 miles to the west, it has some similarity. McConnell's basal rocks, the Indian River "series," resemble the Birch Creek schist, and these are overlain by the Hunker "series," which are not unlike the Fortymile group. The Klondike "series" appears to be made up of altered intrusives.

The writer[b] has described some white crystalline limestones, associated with phyllites, which outcrop along the lower course of White River under the name Nasina "series," and the provisional correlation with the Fortymile group still stands. McConnell[c] adopted the name Nasina, and in a personal letter states that he has traced this same belt of rocks far to the south and inclines to the belief that they may be found to be the equivalent of the sediments included by Dawson in his Shuswap "series."

In northern Alaska the pre-Devonian succession is hardly as well established as the multiplicity of formation names might lead the casual reader to infer. Schrader,[d] after his first season in this district, where he explored the Chandalar and Koyukuk basins, published the following section: Its basal member is the "Rapid" schist, and consists of a biotite schist, often carrying garnet and other metamorphic minerals. The published description does not show any marked difference between these schists and those associated with Schrader's so-called basal granite. The next younger horizon is termed "Amphibolite schist," and is described as fine grained and pale green in color. As this formation is defined it also includes a quartz-mica schist and does not appear to be sharply differentiated from the

[a] McConnell, R. G., The Klondike region: Ann. Rept. Geol. Survey Canada, new ser., vol. 12, 1899, pp. 18A–20A.

[b] Brooks, Alfred H., Reconnaissance in Tanana and White River basins: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 7, 1900, pp. 465–466. In another report, entitled A reconnaissance from Pyramid Harbor to Eagle City, Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, pp. 357–358, the writer grouped all the gold-bearing rocks together under the name "Kotlo series," which would include the Birch Creek, Fortymile, and Rampart groups; but now that more detailed studies have been made, the name "Kotlo" can be entirely eliminated from the stratigraphic nomenclature.

[c] Summary Rept. Geol. Survey Canada for 1900, p. 41.

[d] Schrader, F. C., A reconnaissance along Chandlar and Koyukuk rivers: Twenty-first Ann. Rept. U. S. Geol. Survey, pt. 2, 1900, pp. 472–476.

"Rapid" schist, and its green facies may be an altered intrusive. The "Lake quartzite schist," the next younger formation, is apparently essentially a mica schist, and mineralogically does not differ from the two older formations except in the presence of graphite. It appears that these three formations are lithologically very similar, and, as their relations are so much in doubt, that they might well be grouped together. They seem to form a broad belt of highly metamorphosed sediments with some intrusives, which on the north are succeeded by heavily bedded crystalline limestone and mica schists, termed the Bettles "series." The field distribution indicated on Schrader's map suggests that the schist series and the limestones are unconformable.

Schrader's[a] second journey, during which he crossed the Rocky Mountains to the north, yielded far more definite results, though he was unable to correlate them with those of his previous season.

The Skajit formation he puts at the base of the succession, describing it as made up of heavily bedded crystalline limestones and mica schists. Some obscure organic remains indicate that the Skajit is probably not older than the "Upper Silurian."

A group of mica schists and quartz mica which forms an east-west belt south of the Skajit formation has been called by Schrader the Totsen "series," and is regarded by him as younger than the Skajit formation, but to the writer the evidence would seem stronger that they were older and, in fact, the equivalent of the "Rapids" and "Lake" formations to the east. If this is the case, the Skajit can be correlated with the Bettles. A comparison of the two parallel sections, one on the upper Chandalar and the other on John River, shows in both instances mica schist and quartz-mica schist and greenstone or amphibolite schist on the south, and heavily bedded white crystalline limestone with some mica schist on the north. If the writer's interpretation is correct the correlation of Schrader's pre-Devonian terranes would be as follows:

("Upper Silurian") Skajit formation=Bettles "series."
Totsen "series" and greenstone schist="Rapids," "Lake," and amphibolite schists.

It is of importance to note that this succession bears a close resemblance to that in the oldest sediments of the Yukon-Tanana region already described. The older horizon, made up as it is of mica and quartz schist, is similar to the Birch Creek schist, while the younger, consisting of crystalline limestones and mica schists, bears a resemblance to the Fortymile group.

The close similarity between the succession south and that north of the Yukon suggests the identity of the Fortymile group with the

[a] Schrader, F. C., A reconnaissance in northern Alaska, etc.: Prof. Paper U. S. Geol. Survey No. 20, 1904, pp. 55–62.

Skajit and the Birch Creek with the Totsen. If this proves to be the case and the Skajit is Silurian, as supposed, the Birch Creek and Totsen would fall into the Cambrian or pre-Cambrian.

Mendenhall,[a] in his exploration of the Allen and Kobuk rivers, not attempting to differentiate the semicrystalline rocks which he encountered in his rapid journey, grouped them together under the term "Metamorphic complex." In this group are included schists of various types, limestones, quartzites, and greenstones. The lithology is that of the older terranes of other parts of Alaska, but Mendenhall was unable to ascertain the succession within the complex. The group was traced westward to Kotzebue Sound, and was regarded by Mendenhall in a broad way as the equivalent of the metamorphic terranes of Seward Peninsula.

Nearly the entire bed-rock series of Seward Peninsula is older than the Devonian. The terranes vary from highly crystalline schists to those which are practically unaltered. The stratigraphic succession is now fairly well determined, though only one formation has received a definite assignment to the time scale on paleontologic evidence. The accumulation of geologic data regarding this province has gone on intermittently since 1899, but the close of the season of 1903 saw the completion of the reconnaissance surveys throughout the peninsula. The general succession is as follows, beginning with the oldest: Mica schist and crystalline limestone beds (Kigluaik group), graphitic quartzites (Kuzitrin group), these unconformably(?) overlain by mica schists, then massive limestones, and then mica schists (Nome group). The massive limestone in this latter subdivision carries Silurian fossils and has been called the Port Clarence limestone. The following discussion is based primarily on the writer's own field work in 1900,[b] modified somewhat by Collier, who extended the reconnaissance work in 1901[c] and again in 1903.[d] Other contributors have been Mendenhall, who studied the geology of the southeastern part of the peninsula in 1900,[e] and in 1901[f] touched the northern coast during an exploration already referred to; and Moffit, who completed the reconnaissance mapping of the northeastern portion of the peninsula in 1903.[g]

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[a] Mendenhall, W. C., A reconnaissance from Fort Hamlin to Kotzebue Sound: Prof. Paper U. S. Geol. Survey No. 10, 1902, pp. 31–36.

[b] Brooks, Alfred H., A reconnaissance of the Cape Nome and adjacent gold fields of Seward Peninsula, contained in a special publication of the U. S. Geol. Survey, entitled Reconnaissances in the Cape Nome and Norton Bay regions, Alaska, 1900, pp. 27–41.

[c] Collier, A. J., A reconnaissance of the northwestern portion of Seward Peninsula: Prof. Paper U. S. Geol. Survey No. 2, 1902, pp. 16–24.

[d] Collier, A. J., Hess, F. L., Smith, P. S., and Brooks, A. H., Gold placers of parts of Seward Peninsula, Alaska: Bull. U. S. Geol. Survey No. 328, 1908.

[e] Mendenhall, W. C., A reconnaissance in the Norton Bay region, Alaska, in 1900, contained in a special publication of the U. S. Geol. Survey, entitled Reconnaissances in the Cape Nome and Norton Bay regions, Alaska, 1900, pp. 199–205.

[f] Prof. Paper U. S. Geol. Survey No. 10, 1902.

[g] Moffit, F. H., The Fairhaven gold placers of Seward Peninsula: Bull. U. S. Geol. Survey No. 247, 1905.

The Kigluaik group has been described by the writer as made up of highly crystalline limestones and mica schists, cut by many stocks and dikes of massive granite. Collier's further investigations have shown that the group embraces some gneissoid rocks and some highly graphitic schists. These rocks are succeeded apparently conformably by the Kuzitrin, typically made up of a highly graphitic quartzite. This rock subdivision has not been recognized throughout the area, and may have in part been removed by erosion before the deposition of the succeeding beds, which are apparently unconformable.

The next horizon is a great group of rocks of highly diverse lithological character, called the Nome group. A considerable thickness of mica schists, containing quartz and some albite, forms the basal member of this group, which is succeeded by massive limestone that is in some places semicrystalline. This calcareous member has been called the Port Clarence limestone and is of Silurian age. It may prove to be the equivalent of the Fortymile group and the Skajit formation and suggests that the Kuzitrin or Kigluaik, or both, may be synchronous deposits with the Birch Creek schist and Totsen group.

METAMORPHOSED PALEOZOIC AND POST-PALEOZOIC ROCKS.

It is desirable, before closing this discussion, briefly to pass in review the evidence by which certain of the metamorphosed terranes are assigned to the Paleozoic and younger. Four belts of these younger metamorphic rocks are indicated on the map. The first stretches through southeastern Alaska and probably forms the bed rock throughout the greater part of the unexplored St. Elias Range. It has been identified along the lower Copper River valley and in the Chugach Mountains, and then, bending to the southwest, forms the backbone of the Kenai Peninsula of southeastern Alaska. Silurian,[a] Devonian, Carboniferous, and Lower[b] Cretaceous fossils have been found in these metamorphic rocks of southeastern Alaska. The metamorphic rocks of what appears to be the western end of the same belt have thus far yielded no fossils, and they have been variously assigned to the Paleozoic[c] and the Mesozoic. The intensely folded rocks of the Chugach Mountains may include some pre-Cambrian sediments, but of this no evidence has yet been found.

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[a] Brooks, Alfred H., Preliminary report on the Ketchikan mining district, Alaska: Prof. Paper U. S. Geol. Survey No. 1, 1902, pp. 16–31.

[b] Wright, Fred E. and C. W., unpublished manuscript.

[c] Russell, I. C., Expedition to Mount St. Elias: Nat. Geog. Mag., vol. 3, 1890, pp. 173–174. Schrader, F. C., A reconnaissance of a part of Prince William Sound and Copper River districts in 1898: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 7, 1900, pp. 408–410. Schrader, F. C., and Spencer, A. C., The geology and mineral resources of a portion of the Copper River district, a special publication of the U. S. Geol. Survey, 1901, pp. 34–37. Mendenhall, W. C., A reconnaissance from Resurrection Bay to the Tanana River: Twentieth Ann. Rept. U. S. Geol. Survey, pt. 7, 1900, pp. 265–340. Emerson, B. K., Harriman Alaska Expedition, vol. 4, New York, 1902, pp. 11–54. Martin, G. C., The petroleum fields of the Pacific coast of Alaska: Bull. U. S. Geol. Survey No. 250, 1905, pp. 64. Mendenhall, W. C., The geology of the central Copper River region: Prof. Paper U. S. Geol. Survey No. 41, 1905, pp. 133.

A second belt of metamorphic rocks forms the major part of the Alaska Range, and Ordovician[a] fossils have been found at a horizon which probably occurs near the base of this series, but it is not impossible that pre-Cambrian sediments are also included.

A broad belt of metamorphosed sediments is shown on the map between Yukon and Tanana rivers, and in this are known to be Devonian[b] and Carboniferous, and probably Silurian, horizons. Here, too, pre-Cambrian beds may be included.

Schrader[c] has described a great complex of metamorphic sediments, in which Carboniferous fossils have been found near the top and some doubtful Silurian forms in a limestone occurring near the bottom. Beneath this limestone are mica schists or phyllites, which Schrader has named the Totsen "series,"[d] and which have been described.

These facts indicate that pre-Cambrian horizons will probably not be found among the terranes here classed as metamorphosed rocks, chiefly Paleozoic and Mesozoic, though definite proof of their absence must await detailed surveys.

SUMMARY.

Archean rocks are probably not present in Alaska, though some gneissic areas lying in the Yukon-Tanana region have been provisionally assigned to this period. The proof of the presence of pre-Cambrian sediments is also lacking. Though highly metamorphosed sediments have been found in many different localities, the evidence appears to point to the conclusion that they are for the most part Paleozoic, with some Mesozoic terranes. In the Yukon-Tanana region there are extensive areas of mica schists, termed the Birch Creek schist, which are probably Cambrian or pre-Cambrian. North of the Yukon the same horizon may possibly be recognized in Schrader's Totsen "series." In Seward Peninsula there is an extensive development of metamorphic rocks known to be pre-Silurian. The oldest of these, the Kigluaik group, including a great thickness of mica schists, with some crystalline limestones, appear to be the oldest sediments which have been found in Alaska. This group outcrops along what seems to be the eroded axis of the anticlinal uplift in the heart of the Kigluaik Mountains.

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[a] Brooks, Alfred H., An exploration in the Mount McKinley region, Alaska: Prof. Paper U. S. Geol. Survey. (In manuscript.)

[b] Prindle, L. M., and Hess, F. L., unpublished notes.

[c] Schrader, F. C., A reconnaissance in northern Alaska, etc.: Prof. Paper U. S. Geol. Survey No. 20, 1904, pp. 55–72.

[d] The writer has elsewhere discussed the evidence by which the Totsen group is considered older than the limestone carrying the doubtful Silurian fossils. Compare The geography and geology of Alaska: Prof. Paper U. S. Geol. Survey No. 45, 1906.

The following table indicates, in graphic form, the correlations above suggested:

Provisional table of correlations.

	Yukon-Tanana region.	Klondike.	Northern Alaska.	Seward Peninsula.
Silurian or Ordovician.	Fortymile.	Hunker group and possibly Klondike group.	Skajit.]	Nome group, including Port Clarence limestone.
Cambrian or pre-Cambrian.	Birch Creek.	Indian River group.	Totsen group.	Kuzitrin group. Kigluaik group.

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[1] Grundzüge der physikalischen Geographie von Guatemala, by Carl Sapper. J. Perthes Geog. Anst., Ergänzungsheft, No. 113, 1894, pp. 59, with four maps.

[2] Geology of Chiapas, Tabasco, and the Peninsula of Yucatan, by Carl Sapper. Jour. Geology, vol. 4, 1896, pp. 938–947.

[3] Sinopsis de geología mexicana, by José C. Aguilera. Bol. Inst. geol. de México, Nos. 4, 5, and 6, pt. 2, 1897, pp. 189–250, with geological maps.

[4] Memoir of a tour to northern Mexico, connected with Colonel Doniphan's expedition in 1846 and 1847, by A. Wislizenus. Senate Misc. Docs., No. 26, 1st sess. 30th Cong., 1848, 141 pp., with map.

[5] General report upon the geological collections, by William P. Blake. Report of explorations and surveys to ascertain the most practicable and economical route for a railroad from the Mississippi River to the Pacific Ocean, in 1853–54, vol. 3, pp. 119, with a geological map.

[6] Geological and mineralogical report on portions of Colorado and New Mexico, by Dr. O. Loew. Rept. Chief of Eng. for 1875, pt. 2, Appendix LL, pp. 1017–1036.

[7] Report on the geology of portions of New Mexico and Arizona, examined in 1873, by G. K. Gilbert. Rept. Geog. and Geol. Surveys West 100th Mer., vol. 3, Geology, 1875, pp. 503–566, with atlas sheets.

[8] Notes on the geology of northeastern New Mexico, by Orestes St. John. Bull. U. S. Geol. and Geog. Survey Terr., vol. 2, 1876, pp. 279–308.

[9] Geological report, by J. S. Newberry. Report of the exploring expedition from Santa Fe, N. Mex., to the junction of the Grand and Green rivers of the Great Colorado of the West, in 1859, under the command of Capt. J. N. Macomb, 1876, pp. 152.

[10] Preliminary report of a special geological party operating in Colorado and New Mexico, from Spanish Peaks to the south; field season of 1878, by John J. Stevenson. Rept. Chief of Eng. for 1879, pt. 3. pp. 2249–2259.

[11] Report upon geological examinations in southern Colorado and northern New Mexico during the years 1878 and 1879, by John J. Stevenson. Rept. U. S. Geog. Surveys, W. 100th Mer., vol. 3, Supplement, Geology, 1881, pp. 3–406, with atlas sheets.

[12] The fundamental complex beyond the southern end of the Rocky Mountains, by C. R. Keyes. Am. Geologist, vol. 36, 1905, pp. 112–122.

[13] A reconnaissance of the mineral deposits of New Mexico, by Waldemar Lindgren and L. C. Graton. Bull. U. S. Geol. Survey No. 285, 1906, pp. 74–86.

[14] Report of explorations in 1873 of the Colorado of the West and its tributaries, by J. W. Powell, 1874, pp. 36.

[15] Exploration of the Colorado River of the West and its tributaries, explored in 1869, 1870, 1871, and 1872, by J. W. Powell, 1875, pp. 291.

[16] Report on the geology of portions of Nevada, Utah, California, and Arizona, examined in the years 1871 and 1872, by G. K. Gilbert. Rept. Geog. and Geol. Surveys W. 100th Mer., vol. 3, Geology, 1875, pp. 16–187, with atlas.

[17] Report on the geology of route from St. George, Utah, to Gila River, Arizona, by A. R. Marvine. Idem, pp. 189–225, with atlas sheets.

[18] Report on the geology of the eastern portion of the Uinta Mountains and a region of country adjacent thereto, by J. W. Powell. U. S. Geol. and Geog. Survey Terr., 1876, 218 pp., with atlas.

[19] Pre-Carboniferous strata in the Grand Canyon of the Colorado, Arizona, by Charles D. Walcott. Am. Jour. Sci., 3d ser., vol. 26, 1883, pp. 437–442, 484.

[20] Second contribution to the studies on the Cambrian faunas of North America by C. D. Walcott. Bull. U. S. Geol. Survey No. 30, 1886, 369 pp., 33 pls. See also The Cambrian system in the United States and Canada. Bull. Philos. Soc. Washington, vol. 6, 1884, pp. 98–102.

[21] Stratigraphic position of the *Olenellus* fauna in North America and Europe, by Charles D. Walcott. Am. Jour. Sci., 3d ser., vol. 37, 1889, pp. 374–392; vol. 38, 1889, pp. 29–42.

[22] Study of a line of displacement in the Grand Canyon of the Colorado, in northern Arizona, by C. D. Walcott. Bull. Geol. Soc. America, vol. 1, 1890, pp. 49–64.

[23] Algonkian rocks of the Grand Canyon of the Colorado, by C. D. Walcott. Jour. Geology, vol. 3, 1895, pp. 312–330; Fourteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1894, pp. 497–524.

[24] Manuscript notes by C. R. Van Hise, 1897.

[25] Mining in Arizona, by Wm. P. Blake. Rept. Governor Arizona to Sec. Interior, 1899, p. 142.

[26] Notes on the Colorado district, by W. M. Davis. Am. Jour. Sci., 4th ser., vol. 10, 1900, pp. 251–259.

[27] The geology and vein phenomena of Arizona, by T. B. Comstock. Trans. Am. Inst. Min. Eng., vol. 30, 1900, pp. 1038–1101.

[28] Some salient features in the geology of Arizona, with evidences of shallow seas in Paleozoic time, by Wm. P. Blake. Am. Geologist, vol. 27, 1901, pp. 160–167.

[29] The geology and ore deposits of the Bisbee quadrangle, by F. L. Ransome. Prof. Paper U. S. Geol. Survey No. 21, 1904; Geologic Atlas U. S., folio 112, 1904; Bull. U. S. Geol. Survey No. 213, 1904. Geology of the Globe copper district, Arizona, by F. L. Ransome. Prof. Paper U. S. Geol. Survey No. 12, 1903; Geologic Atlas U. S., folio 111, 1904.

[30] Description of the Bradshaw Mountains quadrangle, by T. A. Jaggar, jr., and Charles Palache. Geologic Atlas U. S., folio 126, 1905.

[31] Copper deposits at Clifton, Ariz., by Waldemar Lindgren. Bull. U. S. Geol. Survey No. 213, 1903, pp. 133–140. Description of the Clifton quadrangle, by Waldemar Lindgren. Geologic Atlas U. S., folio 129, U. S. Geol. Survey, 1905. See also The copper deposits of the Clifton-Morenci district, Arizona, by Waldemar Lindgren. Prof. Paper U. S. Geol. Survey No. 43, 1905.

[32] A comparison of some Paleozoic and pre-Cambrian sections in Arizona, by F. L. Ransome. Paper read before Geol. Soc. Washington, October 30, 1907. Summarized in Science, new ser., vol. 27, 1908, pp. 68–69.

[33] On the geology of the eastern Uinta Mountains, by O. C. Marsh. Am. Jour. Sci., 3d ser., vol. 1, 1871, pp. 191–198.

[34] Report of F. V. Hayden. Prelim. Rept. U. S. Geol. Survey Wyoming, etc., 1872, pp. 1–188.

[35] Descriptive geology, by Arnold Hague and S. F. Emmons. U. S. Geol. Explor. 40th Par., Clarence King, geologist in charge, vol. 2, 1877, 890 pp., 26 plates. See also vol. 1.

[36] Systematic geology, by Clarence King. U. S. Geol. Explor. 40th Par., vol. 1, 1878, 803 pp., with an atlas.

[37] Report on the geology of the Green River district, by A. C. Peale. Eleventh Ann. Rept. U. S. Geol. and Geog. Survey Terr., 1879, pp. 509–646.

[38] Based on unpublished field notes made by C. R. Van Hise in the summer of 1889.

[39] Iron ores in the Uinta Mountains, Utah, by J. M. Boutwell. Bull. U. S. Geol. Survey No. 225, 1904, pp. 221–228.

[40] Stratigraphy of the Uinta Mountains, by Charles P. Berkey. Bull. Geol. Soc. America, vol. 16, 1905, pp. 517–530.

[41] Uinta Mountains, by S. F. Emmons. Bull. Geol. Soc. America, vol. 18, 1907, pp. 287–302.

[42] Stratigraphy and structure of the Uinta Range, by F. B. Weeks. Bull. Geol. Soc. America, vol. 18, 1907, pp. 427–448.

[43] Report of F. V. Hayden. Prelim. Rept. U. S. Geol. Survey Montana, etc., 1872, pp. 13–165, with maps.

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[45] Report of F. V. Hayden, Sixth Ann. Rept. U. S. Geol. Survey Terr., 1873, pp. 11–85.

[46] Report of A. C. Peale. Idem, pp. 97–187.

[47] Report of Frank H. Bradley, geologist of the Snake River division. Idem, pp. 189–271.

[48] Report on the geology of portions of Utah, Nevada, Arizona, and New Mexico, examined in the years 1872 and 1873, by E. E. Howell. Rept. Geog. and Geol. Surveys W. 100th Meridian, vol. 3, Geology, 1875, pp. 227–301, with atlas sheets.

[49] On the Archean rocks of the Wasatch Mountains, by Archibald Geikie. Am. Jour. Sci., 3d ser., vol. 19, 1880, pp. 363–367.

[50] Geology and mining industry of Leadville, Colo., by S. F. Emmons. Mon. U. S. Geol. Survey, vol. 12, pp. 770, pls. 45, atlas of 35 sheets folio.

[51] Progress report on the Park City mining district, Utah, by J. M. Boutwell. Bull. U. S. Geol. Survey No. 213, 1903, pp. 31–40.

[52] The Little Cottonwood granite body of the Wasatch Mountains, by S. F. Emmons. Am. Jour. Sci., 4th ser., vol. 16, 1903, pp. 139–147.

[53] Unpublished manuscript of report on Park City mining district, Utah.

[54] Exploration and survey of the valley of the Great Salt Lake of Utah, including a reconnaissance of a new route through the Rocky Mountains, by Capt. Howard Stansbury. Washington, 1853, 495 pp., atlas of 2 maps. Abstract taken from edition of 1855, published in Philadelphia.

[55] Geological report of the country explored under the twenty-eighth and forty-first parallels of north latitude, in 1853–54, by James Schiel. Reports of explorations and surveys for a railroad from the Mississippi River to the Pacific Ocean, in 1853–54, vol. 2, 1855, pp. 96–107.

[56] Abstract of report on geology of the Eureka district, Nevada, by Arnold Hague. Third Ann. Rept. U. S. Geol. Survey, 1883, pp. 237–290, 8 pls.

[57] Descriptive geology of Nevada south of the fortieth parallel and adjacent portions of California, by J. E. Spurr. Bull. U. S. Geol. Survey No. 208, 1903, pp. 229.

[58] A geologic reconnaissance in southwestern Nevada and eastern California, by Sydney H. Ball. Bull. U. S. Geol. Survey No. 308, 1907, pp. 218.

[59] From manuscript of professional paper on the geological map of North America, by Bailey Willis. In preparation.

[60] Account of an expedition from Pittsburg to the Rocky Mountains, performed in the years 1819 and 1820, by order of the Hon. J. C. Calhoun, Secretary of War, by Maj. Stephen H. Long. Philadelphia, 1823, 2 vols., with an atlas, pp. 503, 442, xcviii.

[61] Geological report, by F. V. Hayden. Third Ann. Rept. U. S. Geol. Survey Terr., embracing Colorado and New Mexico, 1869, pp. 109–199.

[62] Report on the geology of the region traversed by the northern or Middle Park division during the working season of 1873, by Arch. R. Marvine. Seventh Ann. Rept. U. S. Geol. and Geog. Survey Terr., 1874, pp. 83–192, with atlas sheets.

[63] Report on the South Park district during the season of 1873, by A. C. Peale. Idem, pp. 193–273, with atlas sheets.

[64] Report of F. M. Endlich. Idem, pp. 275–361, with atlas sheets.

[65] Report on the geology of a portion of Colorado examined in 1873, by John J. Stevenson. Rept. Geog. and Geol. Surveys W. 100th Mer., vol. 3, Geology, 1875, pp. 303–501, with atlas sheets.

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